AMERICAN SOCIETY OF CIVIL ENGINEERS.

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735.

(Vol. XXXII.—October, 1894.)

HARPER'S FERRY IMPROVEMENT.

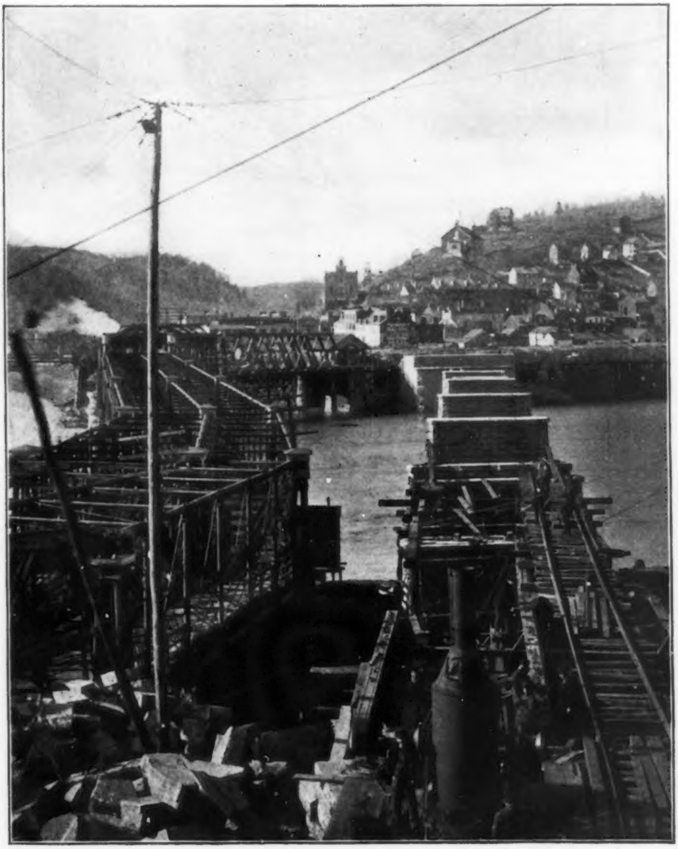
By WILLIAM LEE SISSON, Assoc. M. Am. Soc. C. E.

READ APRIL 18TH, 1894.

At Harper's Ferry, W. Va., 55 miles west of Washington, the three States of Maryland, Virginia and West Virginia come together at the junction of the Potomac and Shenandoah Rivers. Here the Potomac, flowing for some distance southeast, is joined by the Shenandoah, and, breaking through a rugged, picturesque gap in the Blue Ridge, flows eastward nearly at right angles to its former course. The mountains in the vicinity are steep and rugged from their base upwards, the slopes here and there being covered with light growths of timber, and the strata is much distorted and broken. The Potomac at and near this point has an average width of about 1 200 ft., its narrowest part being at its junction with the Shenandoah, where it is only 850 ft. The average depth at extreme low water is about 5 ft., and extreme high water is 36 ft. above this, the rise due to ordinary freshets being from 18 to 20 ft. From Sandy Hook, which is one mile east of Harper's Ferry, the old main line of the Baltimore and Ohio Railroad follows the north bank of the Potomac and the Chesapeake and Ohio Canal

as far as the west side of the mountain gap, where it curves sharply to the left with a 16° curve and crosses the canal and the river on a single-track through bridge of the Bollman type. The north side of the bridge is used for the county road travel. At the east end there is a 16° curve, and at the west end the bridge branches into a Y, the extension of the bridge tangent being used for the Valley Branch and the county road and the other arm of the Y, a curve of 18° being used for the main line. Owing to wooden reinforcing trusses, additional bracing, etc., having been put in to strengthen the original part of the bridge, it is now quite a complicated-looking affair, and its present condition mainly necessitated the change at Harper's Ferry. The old main line then follows the south bank of the Potomac on an iron trestle, reinforced by intermediate wooden bents, for a distance of nearly one-half mile, and, crossing over the old Government canal on a double-track Bollman bridge of 160-ft. span to the foot of the bluffs near Island Park, follows along the West Virginia shore for nearly two miles, at which point it leaves the river. For quite a number of years the Baltimore and Ohio Railroad had been considering the improvement of their line in this vicinity, but it was not until 1892 and after numerous surveys had been made that active measures were taken towards making any change. The main features of the location proposed by Col. James L. Randolph (formerly Chief Engineer) many years ago were adopted, and these, together with a few important changes, constitute the present improvement. In July, 1892, the writer received instructions to make the final location and all plans (except those for superstructure) for the new line between Island Park and Sandy Hook, two miles in all; and also for the new connection to the Valley Branch, one-half mile south from the Ferry, and work was begun one month later.

The change begins at Island Park by replacing 700 ft. of a reverse curve with a tangent to an 8° curve in the old main line at Station 0; thence the line follows with easy alignment and grades along the foot of the bluffs on the West Virginia side to Station 42 + 45.7 where it curves to the left with a 9° 30′ curve to Station 47 + 80 at the west end of the bridge, where it is 8.3 ft. higher than the old main line and 5 ft. above high water; thence crosses the river at an angle of 73° 45′ to its course to Station 56 + 72.82 at the east end of the bridge, where it is 10.9 ft. higher than the old main line. The line then curves to



the right with a 7° curve for 100 ft., when it enters an 815-ft. tunnel, the latter 672 ft. of which is straight; from the east end of tunnel the line is an easy compound curve to where it joins the old main line at Sandy Hook.

Owing to the rugged topography of the country and to the position of certain buildings on the line, it was necessary to establish the new line from Station 43 to 68 + 61 by triangulation. The position of bridge tangent being fixed, the first triangulation was for the curve between 42 + 45.66 and 47 + 80, the P. I. and P. T. of which were inaccessible. A base line was first run from Station 43 on tangent to a point on the bridge tangent extended and from angles taken at each end of it, the station of this point (47 + 41) and its distance from the P. I., the P. I. and the station of P. C. were determined. There was no error.

From a point on the bridge tangent, on the north side of the river, and at the foot of the mountain (which is here perpendicular or overhanging for 300 ft. above the river), the second triangulation was made for the distance across the river between Station 47 + 41 and this point, a base being laid out from the centre line 750 ft. along the foot of the mountain. The error in this distance was .02 of 1 ft. In the third triangulation, owing to the position of the point of the 7° curve (Station 56 + 72.82) and the degree having been first determined, it was necessary, not only to locate the tunnel tangent at the assumed angle (which had been found to be approximately 17°), but also at the calculated distance from the P. C. From this data the tangent of curve was calculated, and together with distance across river to Station 47 + 41, as found by the second triangulation, was taken as a base line, which, in conjunction with the intersection angle and an observed angle at Station 47 + 41, was used to determine a second base line and an angle by means of which to prolong the tunnel tangent eastward. The error of alignment where the lines met in the headings of the tunnel was ½ in., and the intersection afterwards found to be exactly 17°.

The fourth triangulation was made necessary by the steep slopes and roughness of the ground over the tunnel, which did not allow of accurate measurements. The tangent distance of the 7° curve (as assumed in the third triangulation) was taken as a base, from which angles and distances were carefully measured around the foot of the mountain to a point on the center line on the east side. The distance

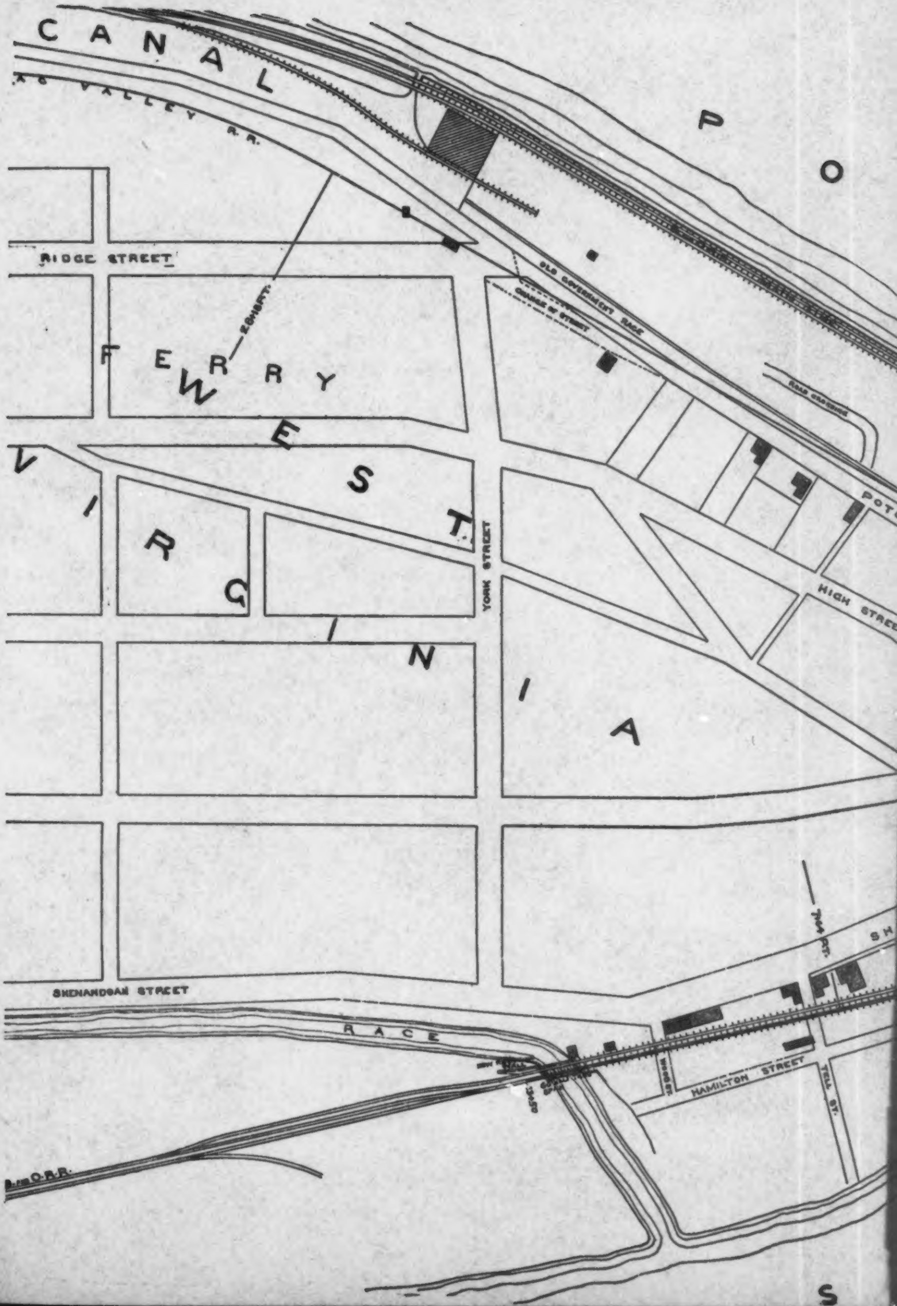
measured through the tunnel afterwards was 0.2 of a foot less than that calculated.

In the fifth triangulation, it was desired to obtain the angle of intersection which the tangent to the reverse curve of the valley connection made with the bridge tangent, the point of intersection being in the river. This was done by taking from each end of a base line, between Station 47 + 41 and a point on the Valley Branch, angles to the bridge tangent and to the Valley Branch. By the sixth triangulation, the distance from the point of intersection of the bridge tangent and the Valley connection to an arbitrary point on the latter was next found, and from this point stations on the Valley connection were determined by direct measurements. There was no error in either of these last two triangulations. It will be observed that in this work all of the triangulations were made assuming the first two to be correct, and that the accuracy of each one was dependent upon that of a preceding one.

The work of construction involved in making the changes for the Harper's Ferry improvement was as follows: From Island Park one-half mile east along the bluffs on the West Virginia side of the river there were 50 000 cu. yds of solid rock cutting, the cuts in some places being 80 ft. high. The rock, limestone and mica schist, when broken up and hauled an average of 2 600 ft. to embankment, made nearly 90 000 cu. yds., an increase of 80 per cent.

The river bridge consists of four deck spans of 85 ft. 6 ins., three through spans of 140 ft., one deck span of 100 ft., and one half-through span of 34 ft. 6 ins., making a total length of 896 ft. 6 ins. The piers of the bridge, eight in number, are set at an angle of 73° 45′ with the center line, and are 6 x 37 ft. on top, and from 34 to 36 ft. high above neat line, and are located directly opposite, and on a line with, the piers of the old bridge, so as to obstruct the water-way as little as possible, and are on a grade of 0.3%, the coping of them being level. They are built of Gettysburg granite and are founded on solid rock. The rock, being generally uneven and full of crevices, was prepared by cutting away the loose or decayed portions of it and then leveling with concrete, mixed in the proportion of 1 part of Portland cement, 2 parts of coarse sharp river sand, and 5 parts of broken stone.

While putting in the foundations the depth of water was about 6 ft. In several cases the Wakefield sheet piling was used for the coffer-dams with good results, both as regards cost and efficiency.


CANAL
VALLEY R.R.
P O
RIDGE STREET
OLD GOVERNMENT RACE
FERRY
WEST
VIRGINIA
YORK STREET
HIGH STREET
SHENANDOAH STREET
RACE
HAMILTON STREET
TELL ST.
B.&O.R.R.
S

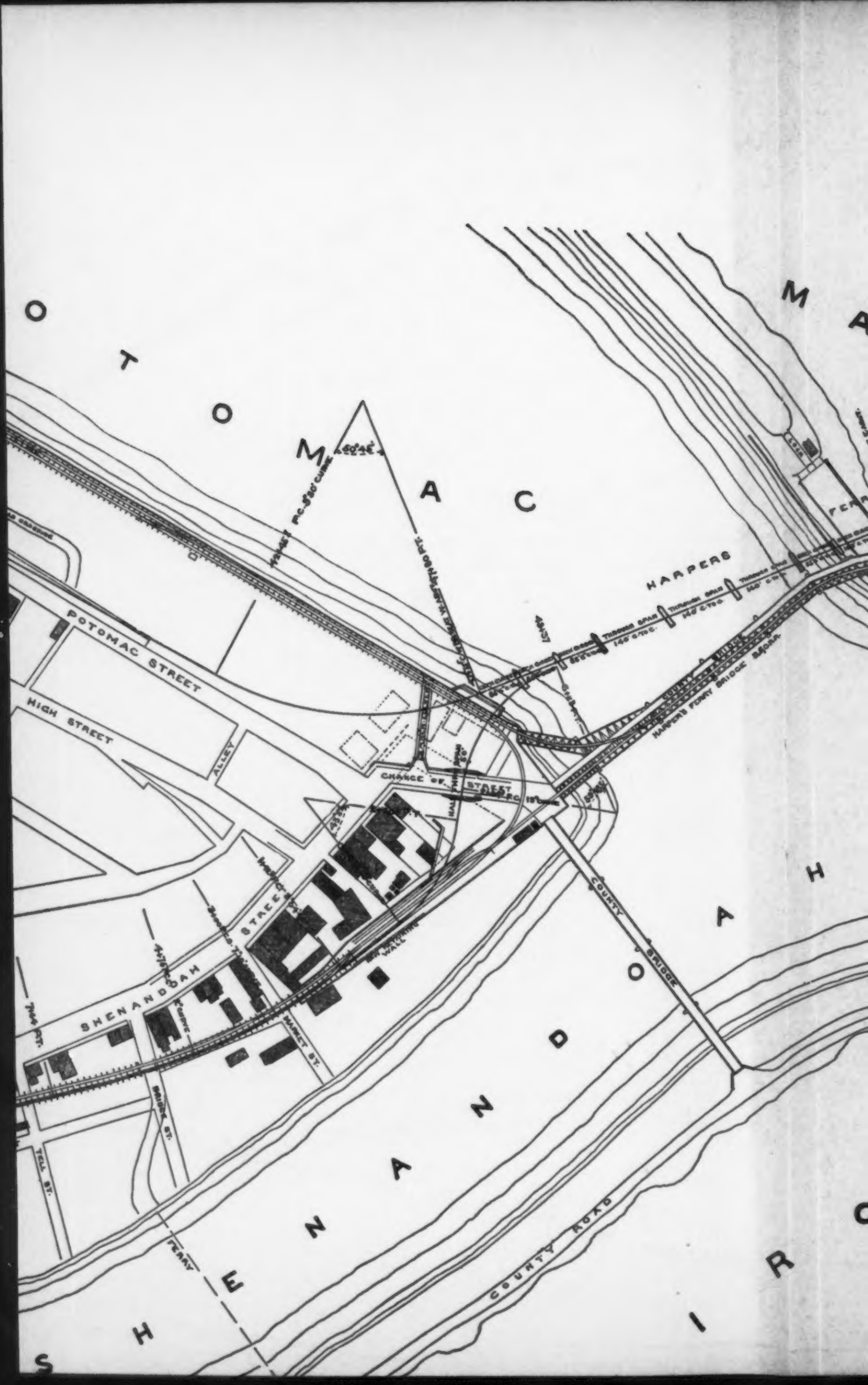
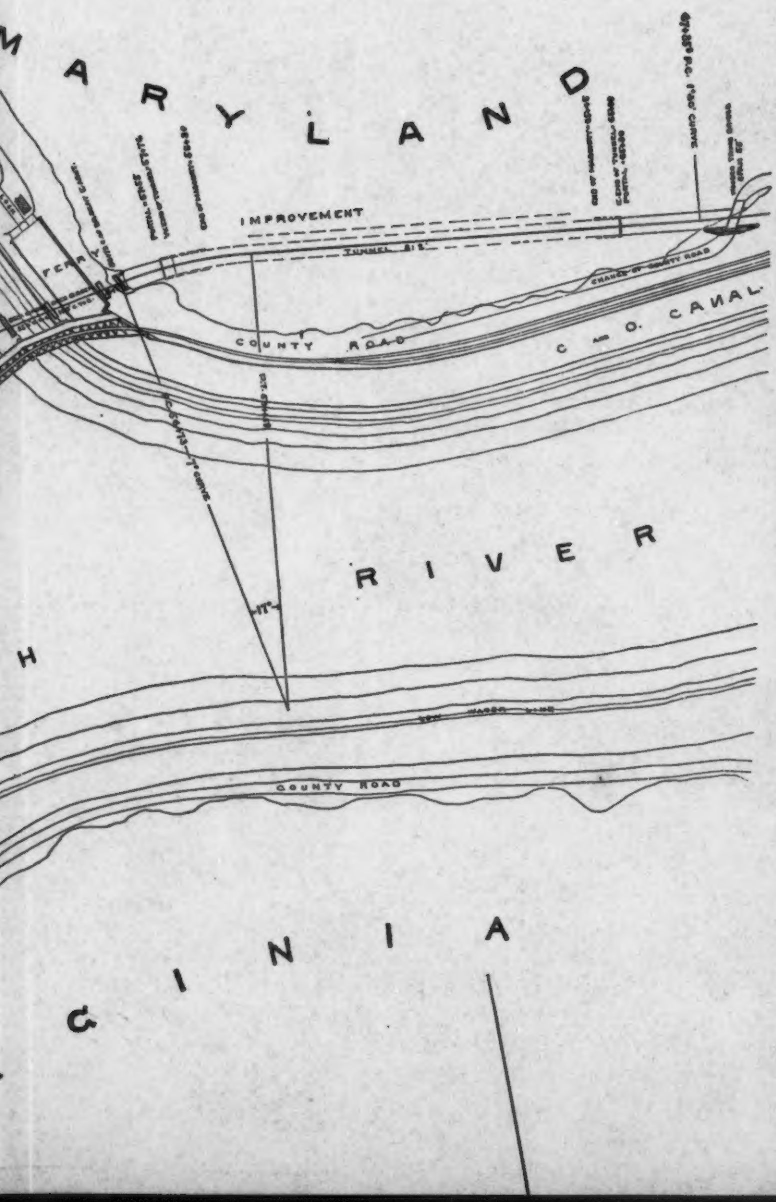
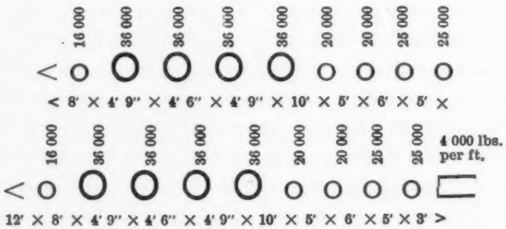

POTOMAC STREET
HIGH STREET
ALLEY
CHANGE OF STREET
HARPERS
SHENANDOAH STREET
MARKET ST.
BRIDGE ST.
TELL ST.
FERRY
COUNTY BRIDGE
HARPER'S FERRY BRIDGE
COUNTY ROAD
S H E N A N D O A H

PLATE XLV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 735.
SISSON ON HARPER'S FERRY IMPROVEMENT



The superstructure is of mild steel, except the eye-bars, pins and rollers, which are of medium steel ; and is designed for a moving load on each track of two 125-ton consolidation engines, coupled, followed by a train load of 4 000 lbs. per linear foot. Weights distributed as follows:



The through spans are single intersection Pratt trusses, 137 ft. *c* to *c* of end pins, 30 ft. high, and 28 ft. 4 ins. *c* to *c* of trusses. The deck spans, of 85 ft. 6 ins., are plate girders, three to each span, 85 ft. out to out of girders, 9 ft. center to center of girders, and 7 ft. 10 ins. deep. The 100-ft. deck span consists of three plate girders 7 ft. 10 ins. deep ; 9 ft. center to center of girders, and 99 ft. 8 ins. out to out. All of the spans are for double track, except the two at the west end of the bridge, which are built for two main line tracks, and the one of the Valley Branch, which here form a Y, the space between the two branches being spanned by plate girders and floored over for a platform.

SUBSTRUCTURE OF BRIDGE.

Excavation of foundation, at 75 cents.		Masonry.									
		First Class, at $10.		Rubble, at $5.		Concrete, at $6.60.		Cement at 85 cents.		Total.	
Cubic yards.	Cost.	Cubic yards.	Cost.	Cubic yards.	Cost.	Cubic yards.	Cost.	Barrels.	Cost.	Cubic yards.	Cost.
2 406	$1 804 50	3 552	$35 520	1 404	$7 020	340	$2 108	4 068	$3 457 80	5 296	$49 910 30

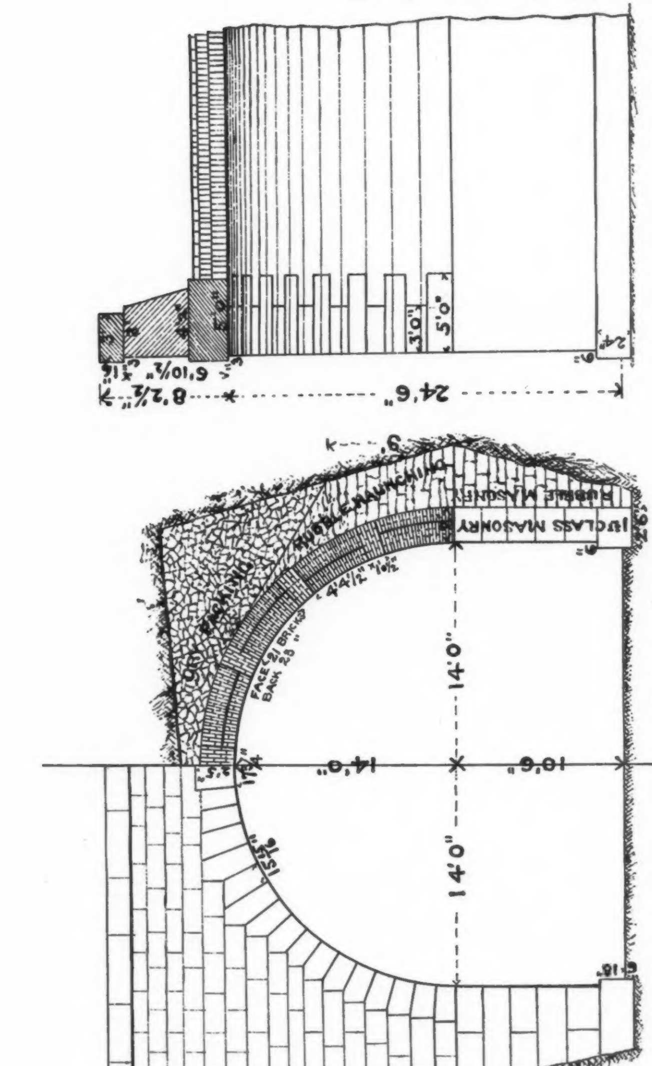
Plate XLVIII is a view of the old and new bridges.

A double-track tunnel 812 ft. long begins 103 ft. from the east end of the bridge and extends through the mountain spur at this point.

The size is 28 ft. wide at the springing line 10 ft. 6 ins. above subgrade and semi-circular arch of 14 ft. radius. The rocks are mica schist with quartz seams, passing into micaceous gneiss, and dipping to the eastward. The strata in places is much contorted and broken. The west portal is at the foot of a cliff 250 ft. high, the approach cut here being 70 ft., and at the end of bridge 40 ft. At the east end the portal slope of the cut is 112 ft. on the upper and 40 ft. on the lower side. The tunnel was driven with Ingersoll-Sergeant drills worked by compressed air supplied by a compressor at the east end of the tunnel, pipes being laid around the foot ef the mountain to supply the west end drills. The headings were 8 x 25 ft., the full top section of the tunnel, and were kept only 15 ft. in advance of the bench, as no timbering was necessary. The rate of progress for heading and bench in the east end was 18 ft. or 401 cu. yds. per week, and in the west end 19 ft., or 423 cu. yds.

From the position of the strata and the presence of large cross seams at both ends of the tunnel it was considered necessary to line 80 ft. of the west, and 45 of the east, end, both portals being in the open cuts about 10 ft. from the ends of the tunnel. The arched portion was of the same size in the clear as the remainder, the arch being built of five rings of bricks, with bench walls of first-class masonry 2 ft. thick, backed with rubble masonry carried up to a point 9 ft. above the springing line, the remainder of packing being stone placed by hand. As it was necessary to lay track through the tunnel, to deliver bridge material at the west end, before the arching was completed, the plan of centers as shown was used. In estimating the actual amount of tunnel excavation, and finding points within the prescribed section, a simple and accurate machine was used, as shown (Plate XLVII). Its weight was about 90 lbs., and cost $4. It was easily moved around by two men. Upon the side pieces, inclined at 45°, were marked degrees from 0 to 90, and upon the lever or pointer, feet and tenths were numbered from the top downward. In cross-sectioning, the foot of the machine was first set at center and grade, and the vertical pieces then plumbed, bringing the center pin at center on the springing line; the pointer was then run out to any desired place, and the distance on the pointer to the center pin and also the angle on the inclined piece noted. In this way the measurements and angles taken above the springing line formed a series of triangles, which were calculated by

PLATE XLVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 735.
SISSON ON HARPER'S FERRY IMPROVEMENT.



LONGITUDINAL SECTION

ELEVATION OF PORTAL — SECTION OF ARCH

TUNNEL EXCAVATION.

	SOLID ROCK, AT 75 CENTS.		TUNNEL EXCAVATION.								CRUSHING BALLAST AT 45 CENTS PER CUBIC YARD.		TOTAL AMOUNT.	
			Per linear foot.				Total, at $2 10.		Overhaul at 1 cent.					
	Cu. yds.	Cost.	Original section. Cu. yds.	Additional section. Cu. yds.	Total section. Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.
West approach...	7 423	$5 567 25	....	....	......	....	......	....	......	....	......	....	7 423	$5 567 25
Tunnel..........	......	....	22.29	2.03	24.32	$51 07	19 868	$41 722 80	132 263	$1 322 63	472	$4 712 40	19 868	47 757 83
East approach....	15 920	11 940 00	....	....	......	....	......	....	......	....	......	....	15 920	11 940 00
Total amounts............													43 211	$65 265 08

TUNNEL MASONRY.

	LINING.				PACKING.						CEMENT.		COST.		PORTALS.	
	First-class masonry, at $9.		Arching, at $9 50.		Rubble, at $5.		Haunching, at $2 50.		Dry packing, at $1 50.							
	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Barrels.	Cost, at 85 cents.	Per lineal foot.	Total.	Cu. yds.	Cost.
West end.........	127	$1 143	270	$2 565 00	101	$505	183	$457 50	967	$1 450 50	650	$552 50	$83 42	$6 673 50	82	$820
East end.........	68	612	145	1 377 50	55	275	105	262 50	248	372 00	355	301 75	71 13	3 200 75	82	820
Total amounts...	195	$1 755	415	$3 942 50	156	$780	288	$720 00	1 215	$1 822 50	1 005	$854 25		$9 874 25	164	$1 640

Total cost of tunnel..$76 779 33

the rule, area = product of the two sides and sine of included angle divided by two.

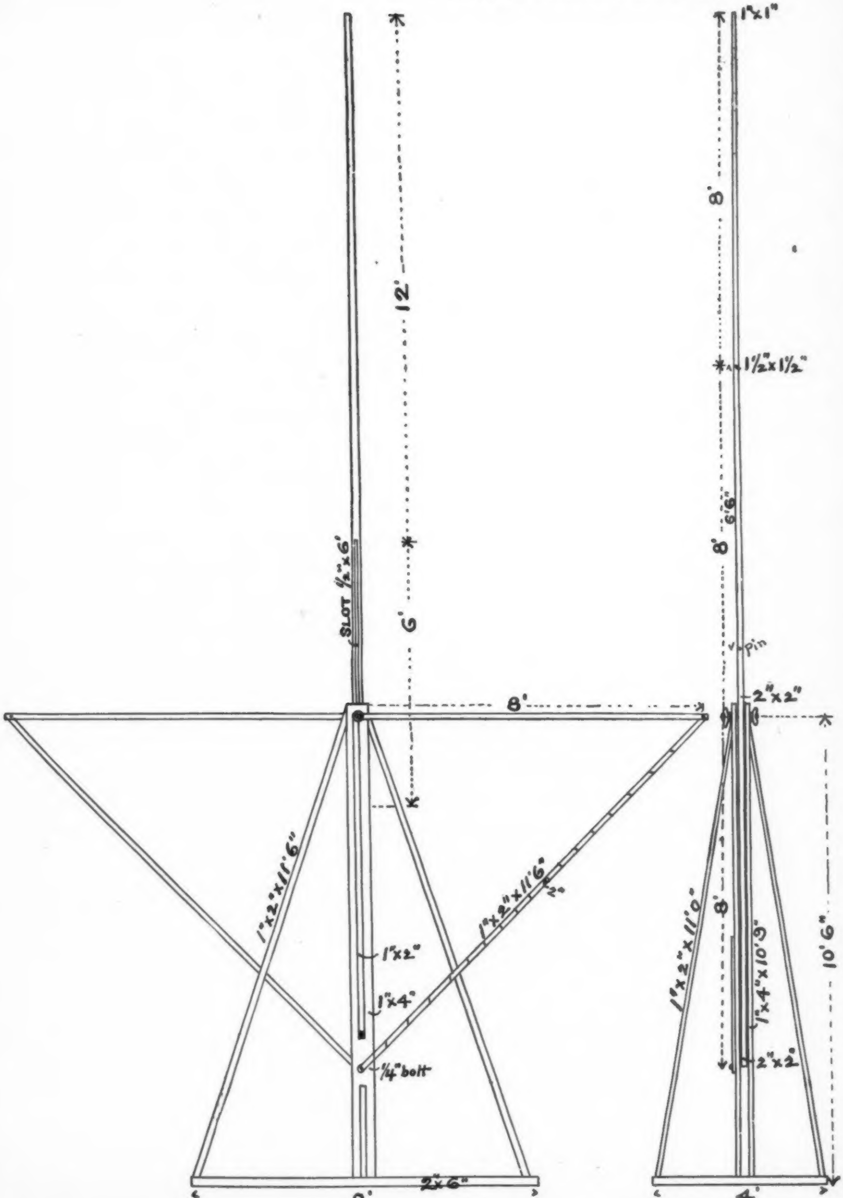
In using the machine merely for finding points within the prescribed section, the inclined and horizontal side pieces were removed and only the pointer used. It will be readily seen that the relative proportions of the different parts insured very accurate results. The disposition of the tunnel material was made as follows: 5 800 cu. yds. was crushed into 10 472 cu. yds. of ballast by a Gates' Crusher No. 4 at the east end, and by a Blake at the west end; then loaded into cars and shipped to different parts of the road. The remainder, 16 482 cu. yds., was used for the embankment east of the tunnel and for raising the county road and the main-line tracks between Sandy Hook and the tunnel.

The county road which originally, from Sandy Hook to the east end of Harper's Ferry bridge, ran parallel to the old main line, and north of it, on the same level, was raised 36 ft. at the east end of the tunnel, to make an overhead crossing of the new line (as shown by Plate XLVIII), and also thrown up against the mountain side, so as to get a 4% grade from this point (Station 68) down to Station 77, where it runs into the old road; at the same time, in order to make the work as light as possible, it was so located that the foot of the slopes of its embankment came just 15 ft. from the new center line at the new grade. The west approach to this crossing, also on a 4% grade, was made by gradually raising the old road between the old main line and the side of the mountain 2 ft. at a time, to keep travel going until the proper height was attained, when additional width, necessary to make a 20-ft. roadway, was obtained by cutting into the steep slope of the mountain, as shown by Plate XLVIII. At the west end of the tunnel the county road was depressed 4 ft. to make an undergrade crossing of the new line, for which a clearance of 12 ft. was required.

CHANGE OF NEW COUNTY ROAD.

Description of Work.		Quantities.	Cost.
Excavation of solid rock............................at	$ 75	5 700 cu. yds.	$4 275 00
Rubble masonry.................................... "	5 00	433 "	2 165 00
Dry rubble wall, for fence............................ "	95	560 "	532 00
Cement.......................................barrels, "	85	400 bbls.	340 00
Wooden Howe Truss Bridge 50-ft. span (in clear), ft. B. M.. "	47 00	12 480 ft. B. M.	585 15
Pounds iron "	03½	623 lbs.	21 80
Total cost of change..			$7 918 95

PLATE XLVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 735.
SISSON ON HARPER'S FERRY IMPROVEMENT.



From Station 73 + 50 to 101, the alignment and grade of the old main line had to be changed to properly connect with the new line, and, while making the change, still maintain the travel. This was done by first laying a third track from Sandy Hook west to Station 77, parallel to and south of the main-line tracks. Between these points the former east-bound track was used as west-bound, and the third track used as east-bound track, after having been connected with the west and east-bound tracks of the main line west of this point (Station 77). The former west-bound track, having been cut loose, was then raised to its full height to conform to the new grade, which was 7 ft. higher at Station 73 + 50 than the old one. The present west-bound track was also, at the same time, gradually raised 9 ins. at a time to the final height; this additional height was run off by means of a heavy grade westward, which was in favor of trains using that track. When the remainder of the work was completed, the road was operated by connecting and distorting both tracks until the new embankment between Station 72 + 50 and 78 was widened out to its full width, which here occupied both of the old tracks; the position of both tracks was then gradually shifted until it finally corresponded to the new alignment. as shown by Plate XLVIII. Between Station 74 + 50 and 76 + 75 a new retaining wall was built along the canal, to catch the extension of the slopes, caused by the additional height of the embankment for the new main line.

The force engaged in raising track was, 1 foreman, 10 men, for 120 days, which, with foreman at $50 per month, and men at $1.15 per day, cost $1 617 69. The amount of material used to make this raise was about 5 000 cu. yds., making the cost per cubic yard about 32 cents. The work was necessarily slow and expensive, as the track had to be kept in good line and surface during the raising of it. The above cost does not include the widening of the embankment between Station 72 + 50 and 78, which, as stated, was done gradually afterwards.

During the raising of the main line, the old county road was also gradually filled, and the travel maintained over it, and the west approach to the overhead crossing at Station 68, until the east approach and crossing were completed when the travel was turned over all of the new road previous to the completion of the change in the main line.

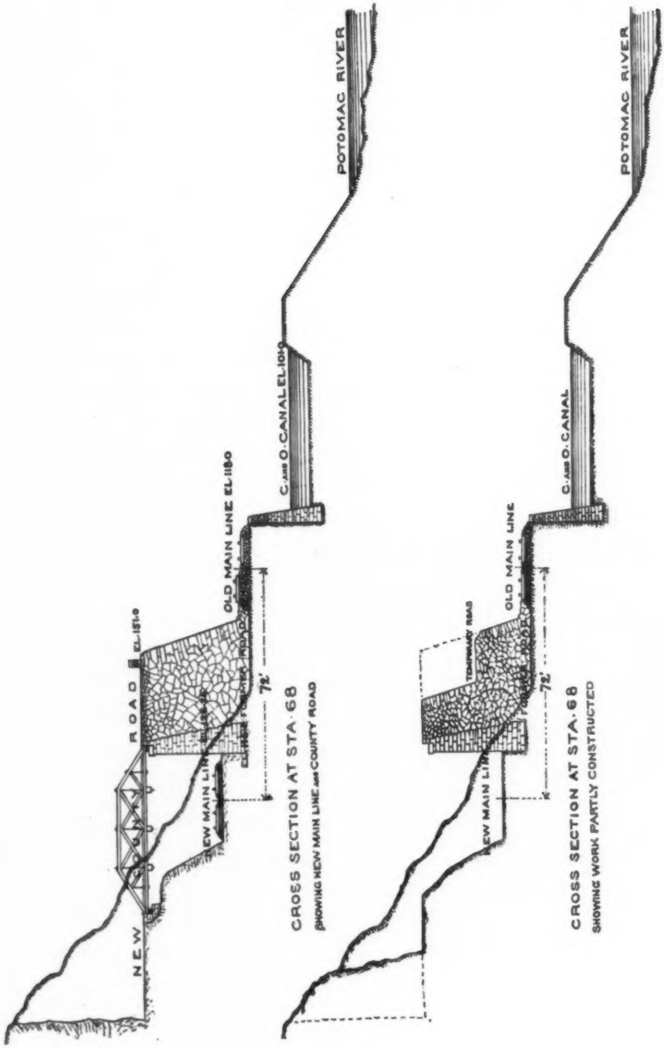
On the West Virginia side of the river at the junction of the new main line and the Valley connection, the width between the river and

Shenandoah Street was insufficient for suitable station grounds, and to obtain the proper width at this point, the street was changed as shown, crossing the new valley connection under grade. The high embankments both on the new main line and connection made necessary the construction of an arch culvert (with 5-ft. bench walls and 5-ft. radius of arch) leading from Shenandoah Street to the river, 186 ft. distant, to provide proper drainage for the lower part of the town in case of an overflow from the Shenandoah River, which at such a time floods this street further south and then flows towards the station. The relative heights of the street and old main line were such, that, to build the arch under the tracks without interfering with trains, it was necessary to make the grade of culvert 1 ft. in 100 ft., which allowed the arch to clear the bottom of the track stringers 6 ins. One of the floor beams, however, had to be removed, as shown on the plan, and temporary timbers put in, resting upon posts placed on each side of the arch, these timbers in turn supporting stringers parallel and close to the regular iron track stringers which alternately broke joint. As the arch was built up, the stringers were blocked up above it and such posts as were in the way removed. The cost, including timber, was $75. The space between the street and the river had in the course of many years been filled with earth from 15 to 20 ft. above the solid rock. At the point where the culvert goes through the old retaining wall, a bed of concrete, 3 ft. thick, 22 ft. wide, and extending back 17 ft. from the old wall and 5 ft. into it, was used; and upon this 3 ft. 6 ins. of rubble the full width of the culvert was laid; the remainder of the culvert was built with ordinary side walls and paving between. The river end of the culvert was built flush with the face of the old retaining wall, which is at an angle of 66° with the axis of the culvert, and on a batter of 3½ ins. to 1 ft.

The cost is as follows:

Rubble	690 cu. yds.,	at	$5 00	$3 450 00
Paving.................	80 " "	"	2 00	160 00
Concrete	75.5 " "	"	4 85	366 17
Brick..................	142 " "	"	9 00	1 278 00
Second-class masonry..	58 " "	"	8 00	464 00
Cement	800 bbls.,	"	0 85	680 00
Total cost of culvert.........................				$6,398 17
Cost per linear foot................................				$34 40

PLATE XLVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 735.
SISSON ON HARPER'S FERRY IMPROVEMENT.



The new Valley connection from Shenandoah Street, 330 ft. south, is embankment, along part of which a retaining wall was necessary, to confine the slopes within the right-of-way limits, the wall being built straight along the property line, and stepped every 10 ft. 6 ins., so as to properly retain the slopes of embankment, the center line of which is a 19° curve.

From the end of this embankment, south 1 150 ft., is a double-track trestle of an average height of 18 ft. above pedestals, or about 7 ft. higher than the old trestle-work. At the north end of the trestle there is a 3° 54′ curve for 190 ft., compounding then into a 7° 10′ for 180 ft., and then a 2° for 100 ft., the remainder being tangent. In some places the old trestle was 18 ins. off of the new alignment, the change being made as the new trestle was built. In building this a temporary single-track trestle was built from Station 1 + 40 to 0 of the Valley connection, and from there on one-half of the permanent trestle was built and used for main track until the other half was raised (the temporary one being then filled in). The new bents were so located that none of the old ones were disturbed until both tracks were in operation. The cost of the trestle was as follows:

Excavation of foundation for pedestals, 350 cu. yds., at 18 cents	$63 00
Pedestals of rubble masonry, 248 cu. yds., at $5	1 240 00
Second-class (caps) masonry, 120 cu. yds., at $8	960 00
Lumber, 468 600 ft. B. M., at $31 75	14 878 05
Iron, 29 910 lbs. (included in price of lumber).	
Total cost	$17 141 05

Cost per linear foot, $14 90.

Iron per M of lumber, 63¾ lbs.

The 60-ft. half-through span at the south end of the trestle was raised by removing (between trains) some of the blocking from under the new trestle (which had been first carried across the bridge on blocking) and jacking the whole span a corresponding distance, until the final height was attained.

From this end of the trestle, south 1 800 ft., the tracks of the Valley Branch were raised, one at a time, to conform to the new grade, which at the trestle was 5 ft. 9½ ins. higher, and 1 800 ft. further south ran

into the old grade. The force engaged in raising the first track was 1 foreman, 10 men, for 45 days, which, at $50 per month for foreman, and $1.15 for men per day, cost $604. The amount of stone required to make this raise was 1 935 cu. yds., making the cost per cubic yard about 31 cents.

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736.

(Vol. XXXII.—October, 1894.)

THE MYRTLE AVENUE IMPROVEMENT ON THE BROOKLYN ELEVATED RAILROAD.

By O. F. NICHOLS, M. Am. Soc. C. E.

READ OCTOBER 3D, 1894.

WITH DISCUSSION.

While heavy grades are quite as objectionable on elevated as on surface railways, the use of double stations, as distinguished from island or intertrack stations, increases operating expenses more rapidly than heavy grades, and introduces a railway problem not often found on surface lines. These double stations are frequently convenient, sometimes necessary, but always expensive. This last-named feature is occasionally overlooked. Few realize, for example, that the Manhattan Railway Company could pay a dividend nearly 1% larger on its stock, if it could use island stations over its whole line.

The radical change of conditions already existing is a serious matter, and it is often difficult to determine the amount of money, time and inconvenience which may be wisely expended to effect a change. It is the purpose of this paper to describe a single attempt to improve

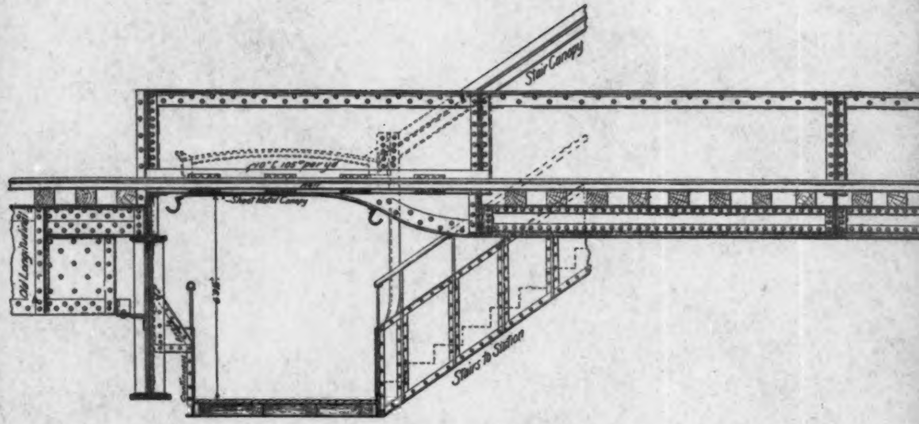
grade and stations on the Brooklyn Elevated Railroad, to enumerate the difficulties encountered, to describe the methods of overcoming them, and to show that this particular change was a profitable one to make.

The conditions as to grade and station location were somewhat peculiar on the Myrtle Avenue line, especially between Bridge Street and Grand Avenue. The grade on the surface of the street reached 4% for some distance east of Raymond Street; this necessitated a heavy grade in the elevated tracks, if the Hudson Avenue and Myrtle Avenue lines were to meet at a common low elevation.

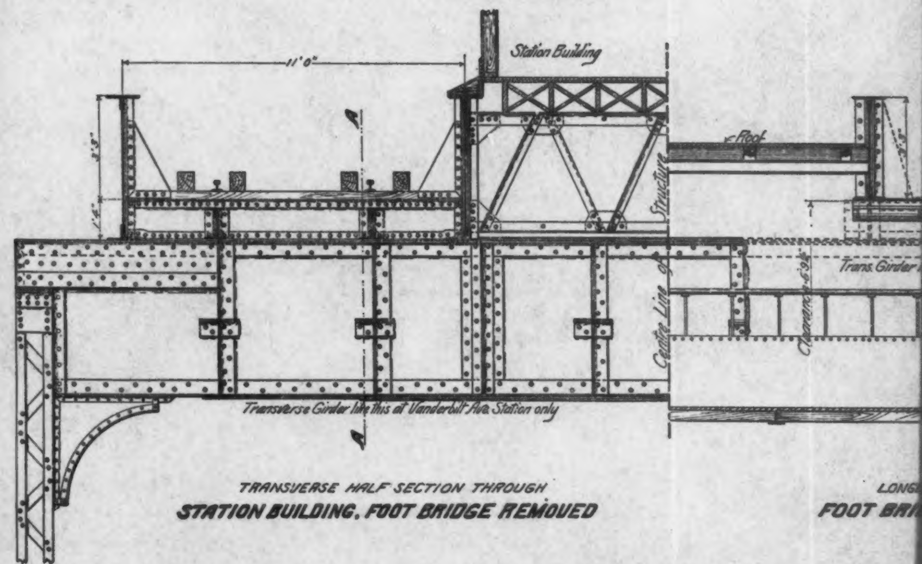
All the other stations on this line were island stations, excepting those at City Hall, Grand, Washington and Vanderbilt avenues. The Grand Avenue station formed a transfer for passengers between the Myrtle Avenue and Lexington Avenue lines through a system of overhead foot bridges. To change the two next adjacent stations to island stations would save much money in operation, change the transfer from Grand to Washington Avenue and make it possible to simplify and economize still further at Grand Avenue at some later time (see map, Plate XLIX).

Through accidental conditions the Washington Avenue station had been built after the road was completed. It was placed on a grade of 1.4%, and, with the Vanderbilt Avenue station, was permanently fixed in position by agreement. Engines frequently stalled in starting heavy trains from the station on this grade, and it seemed necessary to change it if possible. The long stretch (1 700 ft.) of 2.06% grade between Navy Street and Carlton Avenue had caused much trouble and anxiety. More accidents to engines had occurred on this grade than on any other equivalent length of the road.

A careful study of the problem, in 1889, led to the proposition to change the two stations and the steep grade, making the grade line follow the dotted line, as shown on profile (Plate L), and cross Hudson Avenue at a high level; this proposition seemed impracticable on many accounts at the time, and the entire project was abandoned to be taken up again early in 1893. The travel then having increased so as to crowd the terminal station at the Bridge, it was proposed to run five car trains over Myrtle Avenue, and to make it easier to do this it was decided to cut the heavy grade in two, lengthways, lessening and lengthening the upper part of it. The steep grade would then be



SECTION A-A

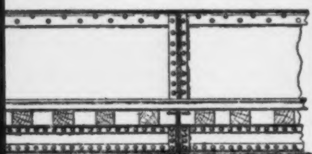


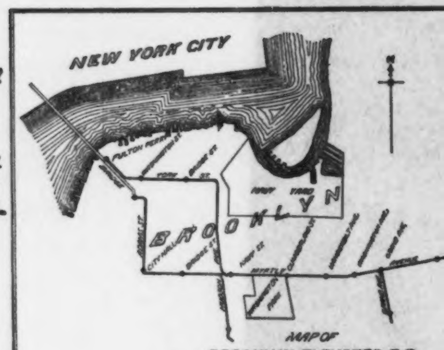
TRANSVERSE HALF SECTION THROUGH
STATION BUILDING, FOOT BRIDGE REMOVED

LONG
FOOT BRI

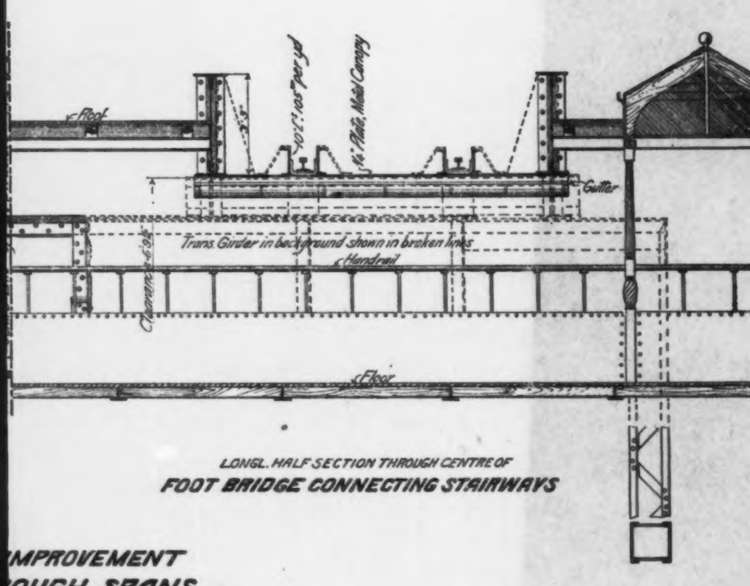
MYRTLE AVE. IMPROVEMENT
DETAILS OF THROUGH SPANS

PLATE XLIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.
NICHOLS ON IMPROVEMENT ON BROOKLYN ELEVATED RAILRO





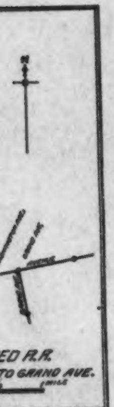
MAP OF
BROOKLYN ELEVATED R.R.
FROM THE BRIDGE AND FERRY TO GRAND AV

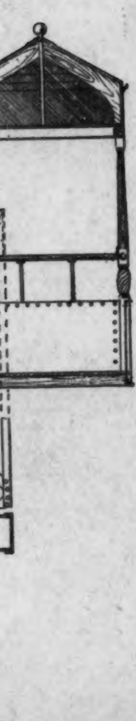


LONGL. HALF SECTION THROUGH CENTRE OF
FOOT BRIDGE CONNECTING STAIRWAYS

MPROVEMENT
OUGH SPANS

ED RAILROAD.





about the same length as two or three other pieces of the same gradient on other branches of the road, and it would then be possible to place a station at Cumberland Street.

Studies were made for changing the grade below Carlton Avenue and above Washington Avenue, for changing the two stations to island stations, and for providing a new station at Cumberland Street. The steady increase of travel in 1892, and well into 1893, fell off, owing to the financial depression of the early summer and the advent of the use of electricity on the surface lines. Short riders were more attracted by the newer method of travel, and it was decided to complete the iron work only for the new station, leaving the balance of the work on this Cumberland Street station to be finished at some later day.

The problem was so complicated that it was difficult to make a very close estimate of the cost of the work. In the preliminary report $40 000 was named as the probable cost of the entire improvement.

The lowering of the grade between bents 68 and 92 was regarded as the most serious portion of the work, since it must be done without interference with travel, and on account of the importance of doing it in such manner and with such appliances as should command the confidence of the public without attracting too much attention. Any failure in this respect might easily double the cost of the work from loss of passengers alone.

Plans and estimates for doing the work were sought from experienced bridge erectors; nothing, however, resulted in the way of plans more satisfactory than those already prepared, and no one would agree to undertake the execution of the work on terms other than a percentage on its cost, which seemed too indefinite for acceptance. It was, therefore, decided to purchase the tools and materials and do the work by day labor under the supervision of the roadmaster, who had had much experience in changes of elevated railway structures, both in New York and Brooklyn.

The earlier plans proposed to cut a section out of each column a little above its base, splicing the two parts of the column together with plates riveted on the sides; this avoided the awkward cutting of columns, about 20 in number, on which the "drop end" girders extended down the side of the column more than 2 ft.; it also retained the rigid connections between columns and girders, which it then seemed wise to rely upon, in part at least, as a safeguard against

any overturning tendency. It was desirable to do the work during the months of May and June, when the weather would be most favorable, and the travel lighter than in the early spring months, and it was important to finish the changes in the main structure and track system before the cables and wires of the surface trolley road underneath were attached to the structure and actually in use, or, say, before the middle of August.

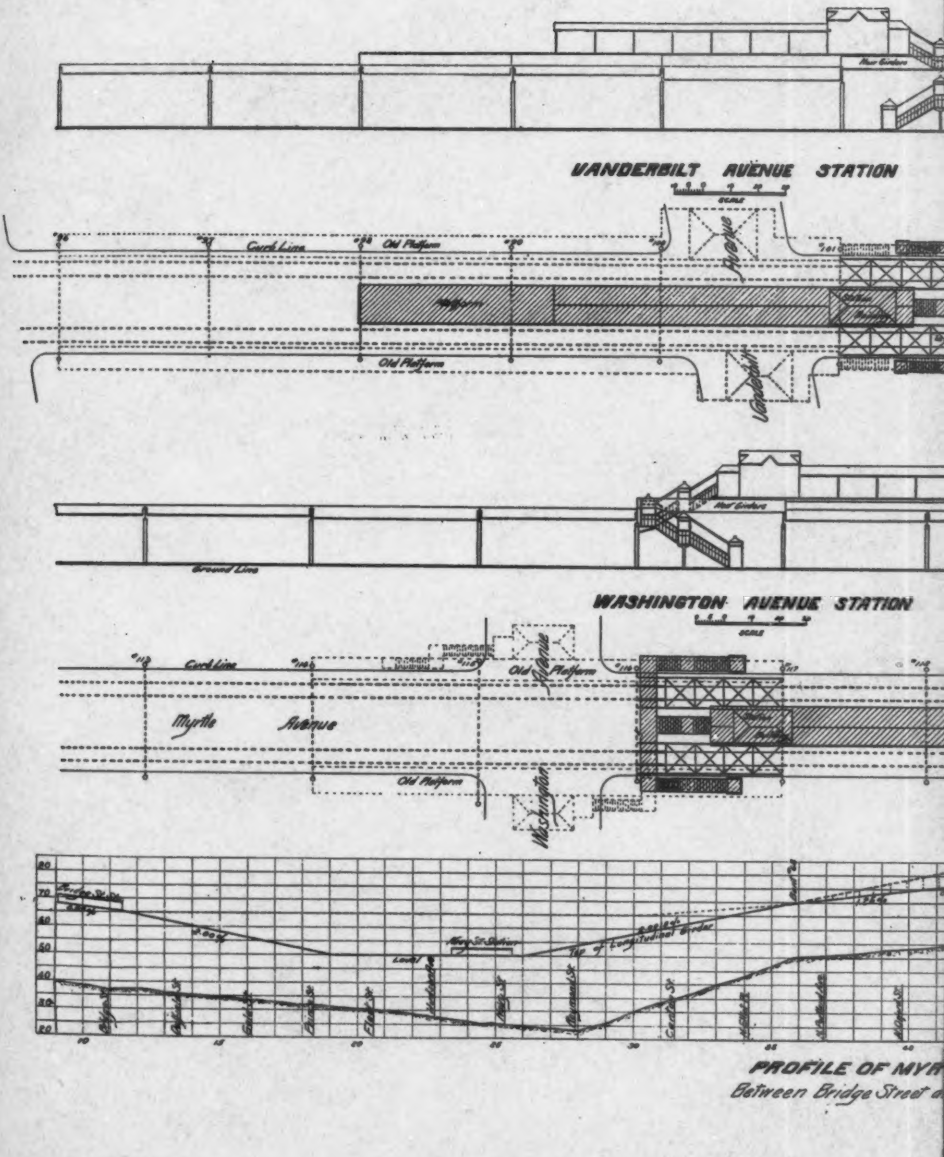
Considerable time was lost in attempting to secure a cold saw for cutting the columns. Two of the saw-makers took little, if any, interest in the problem; the makers of the Higley saw were much interested and designed a tool which promised to satify the conditions fully. The saw was designed to work by hand or by electric power on an iron frame clamped to the side of the column; the saw blade, 12 ins. in diameter, was arranged to pass through the column, cutting one channel completely off in transit. It was estimated that the saw would make each cut in less than half an hour. The weight of the machine was about 600 lbs., and its cost $500. The delay necessary to make the saw and the demonstration by actual test that all the channels actually cut could be cut off by hand for about the price of the saw, led finally to the abandonment of machine cutting.

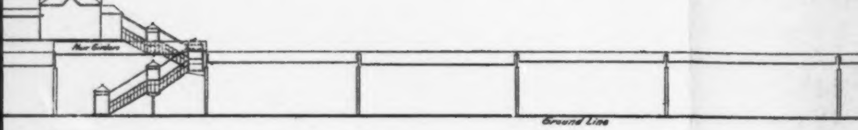
The saw was first proposed when the cutting at the base was considered. Only one-fourth of the cutting was required at top of columns, while the difficulties and delays in handling a heavy machine would have been increased by raising it from the ground.

The plan of cutting at the top of columns was developed partly from the fact that the work of cutting and splicing the columns would be done at a disadvantage, unless a system of blocking and lowering could be devised which would leave a large free space about the base of columns.

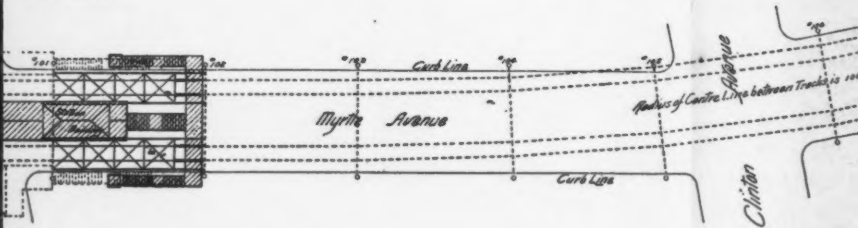
The street roadway must be kept clear, so as to leave space for vehicles between the blocking and the surface car tracks. This became more important when the surface road commenced the relaying of its tracks and the repavement of the street about them almost simultaneously with the commencement of the work on the structure.

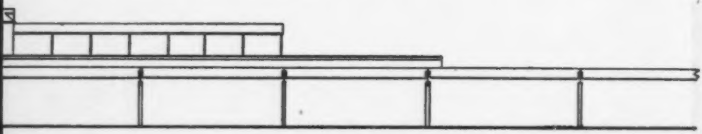
The columns were firmly fixed by rust joint into heavy cast-iron bases about 3 ft. square, and these were bolted to brick masonry piers. It was finally decided to take advantage of the columns themselves to steady the lowering apparatus, and to cut the columns off at the top.

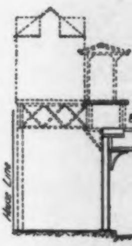

VANDERBILT AVENUE STATION
SCALE
Curb Line
Old Platform
Platform
Avenue
Vanderbilt
Ground Line
WASHINGTON AVENUE STATION
SCALE
Curb Line
Old Platform
Myrtle
Avenue
Washington
Bridge St.
Navy St. Station
Top of Longitudinal Girder
PROFILE OF MYR
Between Bridge Street a



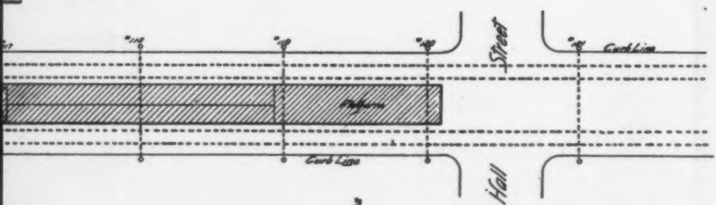
STATION

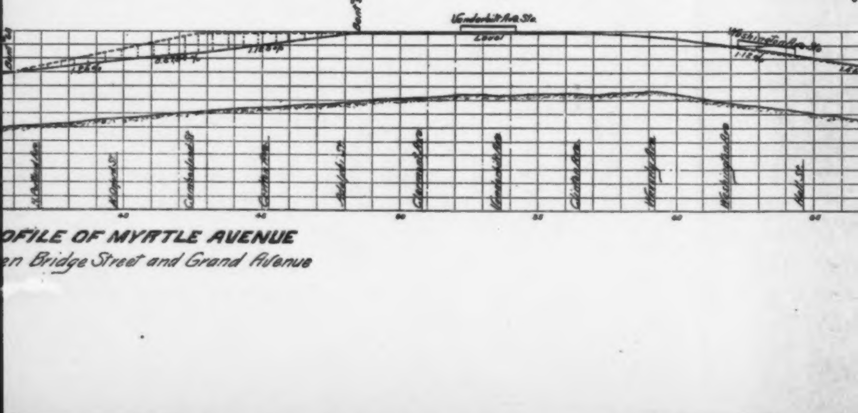






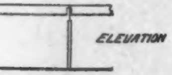
NUE STATION

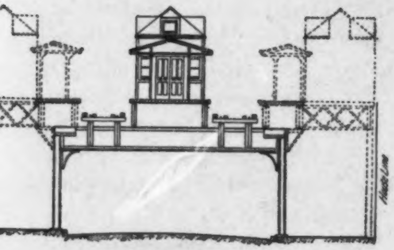




OFILE OF MYRTLE AVENUE
en Bridge Street and Grand Avenue

PLATE L.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.
…MPROVEMENT ON BROOKLYN ELEVATED RAILROAD.





SECTION – BENT No 118
Stairs to Street not shown

SCALE

The yellow pine timber for lowering was ordered directly from the south from economical motives and to secure good sound heart timber, to resist the heavy unit stresses liable to come upon it. All of the vertical sticks were suspended from the transverse girders; this avoided all handling of these timbers during the progress of the work. The larger vertical timbers were secured to the girders by built T-irons, bolted to the sticks and to the girders to aid in preventing tilting of the girders. Two channel irons, held together by four bolts, formed clamps placed near top and bottom of columns, to steady the timbers; the middle bolts served as separators, and the end bolts as guides. A space was left between the back of column and the corresponding bolt, to allow the column to spring out $\frac{5}{8}$ in. at the top when the girder was lowered into the back channel of the column; this space was filled by wooden wedges at other times.

Two 60-ton hydraulic jacks were used, one under each of the smaller sticks at each end of the girder. When the larger timbers were placed in position they were left 12 ins. short of reaching the main blocking. This space was filled by three carefully dressed blocks 4 ins. thick, 14 ins. wide and 3 ft. long, bolted through edgeways, to prevent splitting.

The brackets were cut out between columns and girders, the blocking and vertical timbers were carefully placed and lock wedges driven under the large timbers, to give a firm and uniform support. The side plates and angles forming caps of the columns were then removed and placed in correct position for new caps, the rivet holes having been previously drilled. The horizontal seat plates were cut out to fit the back channel which was to be left intact; the edges of the vertical angles at ends of girders were also cut, to make sure of their entering the channel freely.

When the sides of the column cap were secured in new position the inside channel of the column was cut off with a heavy diamond-point tool held by one man while another struck it with a heavy hammer; the diamond-point was made of $1\frac{1}{4}$-in. octagon steel about 2 ft. long. Two men would frequently cut a channel off in two hours; the surface of the cut was afterwards dressed up with hand chisel and hammer.

The men worked at top of columns on a platform about 6 ft. square, formed of loose planks, enclosing the columns resting on two joists

suspended by ropes, one from the track timbers and the other from a cross-tie clamped to the girder over the column. As soon as the new column cap was completed by adding its top plate, blocks 6 x 6 x 18 ins. were piled on it in pairs and wedged under the end of girder, to give additional support.

The cutting of the columns was started at the summit of the grade where it amounted to 5 ft. $7\frac{1}{4}$ ins. When the columns of three bents had been cut, the girders of these bents were at once lowered 4 ins.; the columns were sprung out by slacking the wedges at the back clamp bolt and driving other wedges between the column and the heavy timber; the girders at once entered the channels, which from this on formed guides to steady and keep them in place. The cutting was extended until the girders at the summit could be lowered 12 ins. All the cutting was then completed and the general lowering began, commencing at the easterly or upper end, care being taken not to produce grades exceeding 0.6% and to gradually reduce the heavy grade on the westerly end to its new limits.

The lowering was done by two gangs of six men each, one on each side of the street at each of the columns; the superintendent with one gang, and the assistant with the other. Two men handled the jack, two the blocking, and the other two adjusted the clamps, which were never allowed to get too slack or drop out of position.

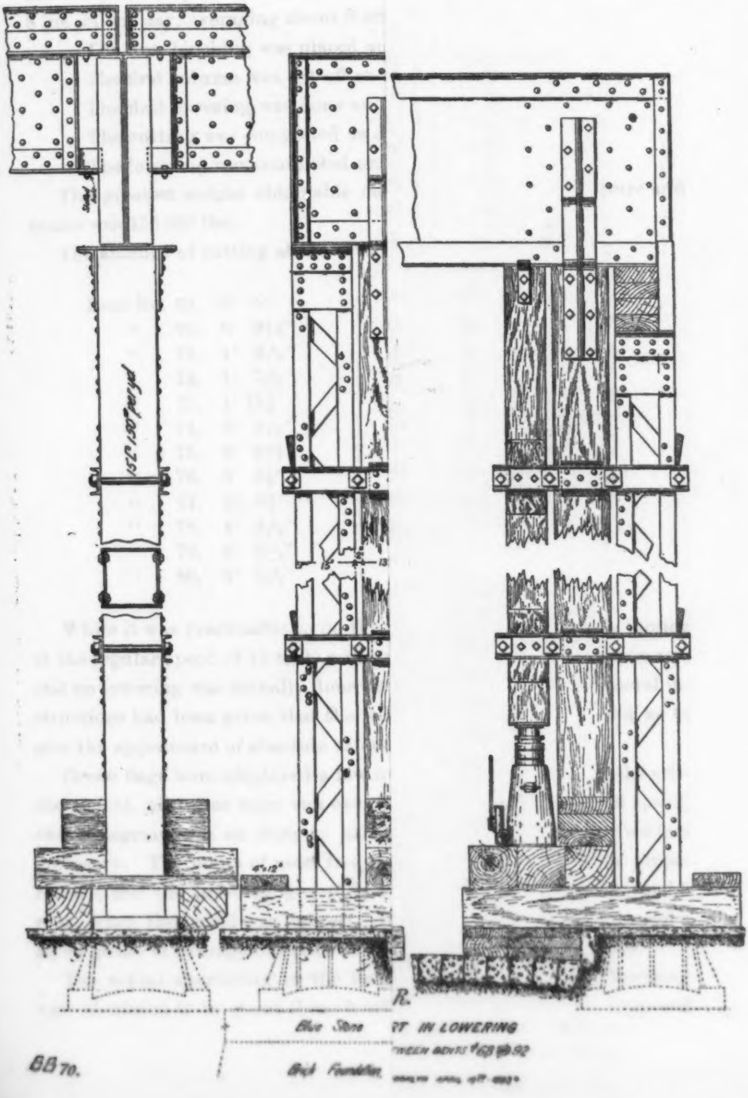
The jacks had 12 ins. lift, and had let-off cocks by which the lowering could be checked at any point by the slight movement of a key in the hand of the foreman of the jack. They weighed 300 lbs. each, and were easily carried from column to column by four men, using a hand spike put through rope slings in the handles.

In lowering, the jacks were set up to relieve the 4-in. block; this was then backed out, followed by a block 1 in. thinner, and this in turn backed out, followed by a thinner one in the same manner. In case of accident to the jack the vertical timber could not, therefore, drop more than 1 in.

When each girder had been lowered the first 12 ins., it became necessary, if it was to go lower, to saw off the heavy vertical timbers. The girders were then blocked directly on the iron column, the jacks slacked and the timber sawed off 16 ins. A lowering of 4 ins. again brought the blocking to the standard of 12 ins.

When a 4-in. drop was carried over the entire line, two girders, one

PLATE LI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.
…VEMENT ON BROOKLYN ELEVATED RAILROAD.



BB 70.

The yellow pine timber for lowering was ordered directly from the south from economical motives and to secure good sound heart timber, to resist the heavy unit stresses liable to come upon it. All of the vertical sticks were suspended from the transverse girders; this avoided all handling of these timbers during the progress of the work. The larger vertical timbers were secured to the girders by built T-irons, bolted to the sticks and to the girders to aid in preventing tilting of the girders. Two channel irons, held together by four bolts, formed clamps placed near top and bottom of columns, to steady the timbers; the middle bolts served as separators, and the end bolts as guides. A space was left between the back of column and the corresponding bolt, to allow the column to spring out $\frac{5}{8}$ in. at the top when the girder was lowered into the back channel of the column; this space was filled by wooden wedges at other times.

Two 60-ton hydraulic jacks were used, one under each of the smaller sticks at each end of the girder. When the larger timbers were placed in position they were left 12 ins. short of reaching the main blocking. This space was filled by three carefully dressed blocks 4 ins. thick, 14 ins. wide and 3 ft. long, bolted through edgeways, to prevent splitting.

The brackets were cut out between columns and girders, the blocking and vertical timbers were carefully placed and lock wedges driven under the large timbers, to give a firm and uniform support. The side plates and angles forming caps of the columns were then removed and placed in correct position for new caps, the rivet holes having been previously drilled. The horizontal seat plates were cut out to fit the back channel which was to be left intact; the edges of the vertical angles at ends of girders were also cut, to make sure of their entering the channel freely.

When the sides of the column cap were secured in new position the inside channel of the column was cut off with a heavy diamond-point tool held by one man while another struck it with a heavy hammer; the diamond-point was made of $1\frac{1}{4}$-in. octagon steel about 2 ft. long. Two men would frequently cut a channel off in two hours; the surface of the cut was afterwards dressed up with hand chisel and hammer.

The men worked at top of columns on a platform about 6 ft. square, formed of loose planks, enclosing the columns resting on two joists

suspended by ropes, one from the track timbers and the other from a cross-tie clamped to the girder over the column. As soon as the new column cap was completed by adding its top plate, blocks 6 x 6 x 18 ins. were piled on it in pairs and wedged under the end of girder, to give additional support.

The cutting of the columns was started at the summit of the grade where it amounted to 5 ft. $7\frac{1}{4}$ ins. When the columns of three bents had been cut, the girders of these bents were at once lowered 4 ins.; the columns were sprung out by slacking the wedges at the back clamp bolt and driving other wedges between the column and the heavy timber; the girders at once entered the channels, which from this on formed guides to steady and keep them in place. The cutting was extended until the girders at the summit could be lowered 12 ins. All the cutting was then completed and the general lowering began, commencing at the easterly or upper end, care being taken not to produce grades exceeding 0.6% and to gradually reduce the heavy grade on the westerly end to its new limits.

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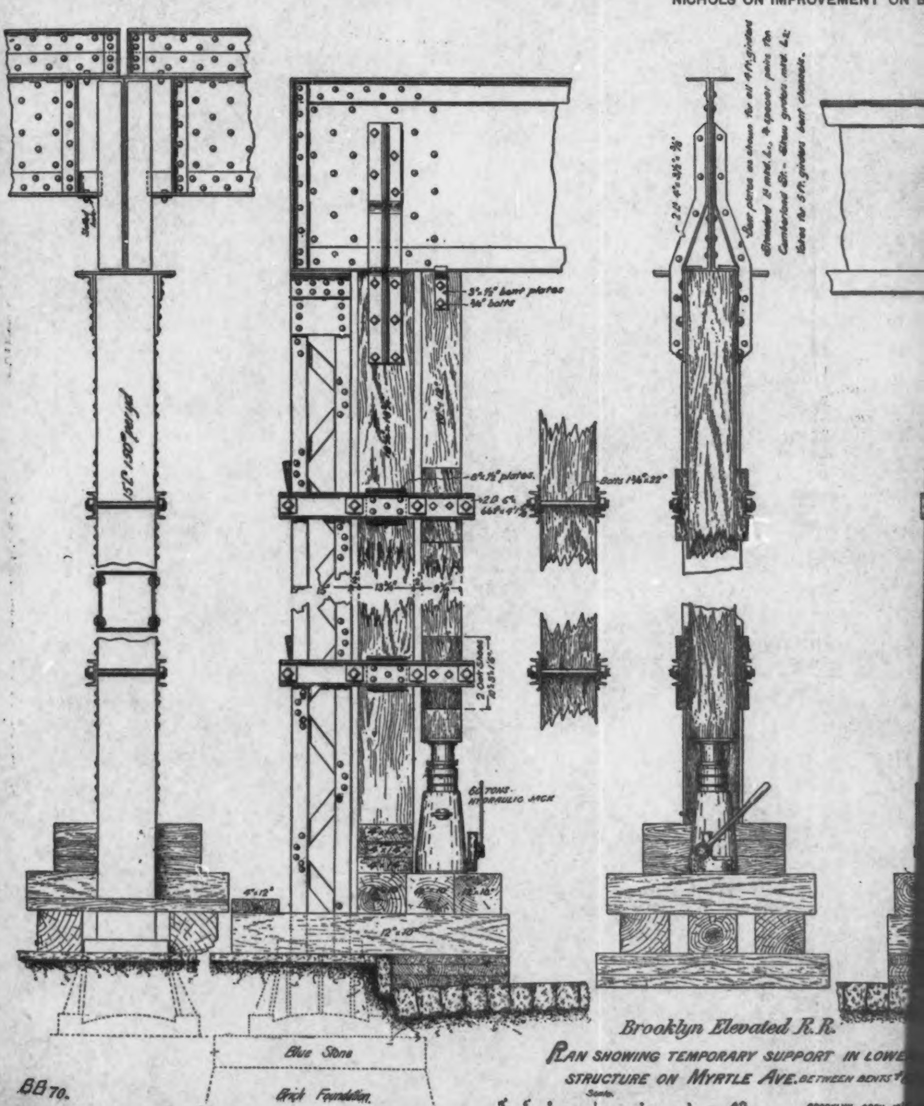
The jacks had 12 ins. lift, and had let-off cocks by which the lowering could be checked at any point by the slight movement of a key in the hand of the foreman of the jack. They weighed 300 lbs. each, and were easily carried from column to column by four men, using a hand spike put through rope slings in the handles.

In lowering, the jacks were set up to relieve the 4-in. block; this was then backed out, followed by a block 1 in. thinner, and this in turn backed out, followed by a thinner one in the same manner. In case of accident to the jack the vertical timber could not, therefore, drop more than 1 in.

When each girder had been lowered the first 12 ins., it became necessary, if it was to go lower, to saw off the heavy vertical timbers. The girders were then blocked directly on the iron column, the jacks slacked and the timber sawed off 16 ins. A lowering of 4 ins. again brought the blocking to the standard of 12 ins.

When a 4-in. drop was carried over the entire line, two girders, one

PLATE
TRANS. AM. SOC
VOL. XXXI
NICHOLS ON IMPROVEMENT ON B

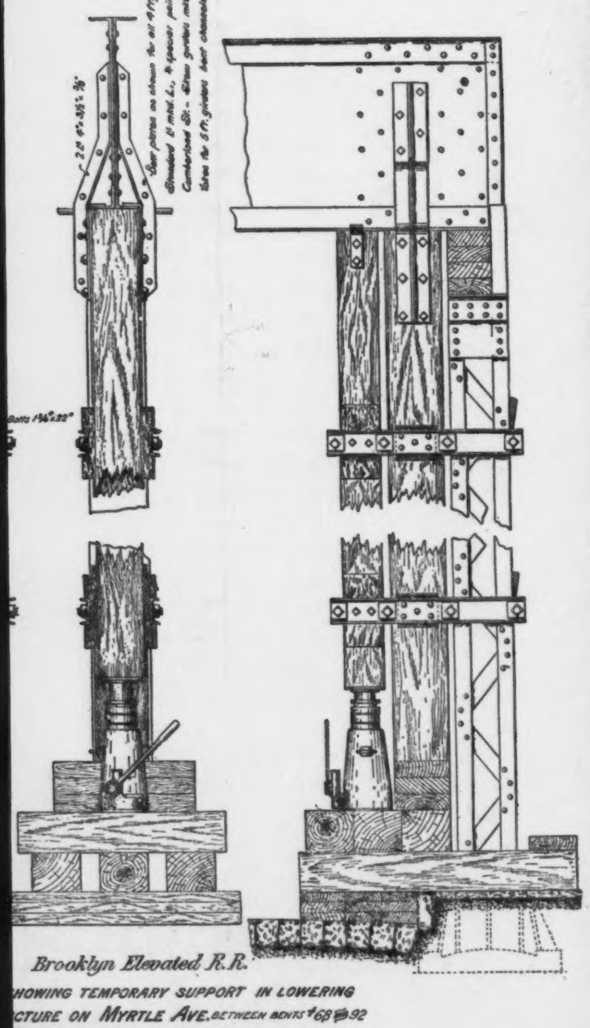


Brooklyn Elevated R.R.
PLAN SHOWING TEMPORARY SUPPORT IN LOWE
STRUCTURE ON MYRTLE AVE. BETWEEN BENTS
BROOKLYN APRIL

PLATE LI.

TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.

NICHOLS ON IMPROVEMENT ON BROOKLYN ELEVATED RAILROAD.



Brooklyn Elevated R.R.

[S]HOWING TEMPORARY SUPPORT IN LOWERING [STRU]CTURE ON MYRTLE AVE. BETWEEN BENTS #68 & 92

2 3 4 ft.

BROOKLYN APRIL 19TH 1893

at each end, would generally reach their final bearing at each trip. Such a drop was once carried over the line in three and a half hours, and a second drop completed the same day, or the structure lowered 8 ins. in one day, averaging about 8 minutes to each column.

The first blocking was placed on June 1st, 1893.

The first column was cut off on June 7th, 1893.

The first lowering was done on June 13th, 1893.

The cutting was completed on June 22d, 1893.

The lowering was completed on July 1st, 1893.

The greatest weight obtainable on any column from structure and trains was 156 000 lbs.

The amount of cutting at the several bents was as follows :

Bent No.	69,	0′ 5″	Bent No.	81,	5′ $7\frac{1}{4}$″
"	70,	0′ $9\frac{13}{16}$″	"	82,	5′ $4\frac{7}{8}$″
"	71,	1′ $3\frac{1}{16}$″	"	83,	4′ $11\frac{7}{16}$″
"	72,	1′ $7\frac{7}{16}$″	"	84,	4′ $5\frac{3}{8}$″
"	73,	1′ $11\frac{7}{8}$″	"	85,	3′ $11\frac{9}{16}$″
"	74,	2′ $4\frac{5}{16}$″	"	86,	3′ $3\frac{7}{8}$″
"	75,	2′ $9\frac{15}{16}$″	"	87,	2′ $7\frac{1}{4}$″
"	76,	3′ $3\frac{5}{8}$″	"	88,	1′ $11\frac{7}{16}$″
"	77,	3′ $8\frac{3}{4}$″	"	89,	1′ $3\frac{3}{4}$″
"	78,	4′ $4\frac{9}{16}$″	"	90,	0′ $8\frac{1}{8}$″
"	79,	5′ $0\frac{7}{16}$″	"	91,	0′ 3″
"	80,	5′ $5\frac{7}{16}$″			

While it was practicable to do the entire work with trains in motion at the regular speed of 15 to 20 miles per hour, this was not necessary, and no lowering was actually done under a moving train. General instructions had been given that the work should be so conducted as to give the appearance of absolute safety as well as to secure it.

Green flags were displayed a few hundred feet each side of the critical points, all trains were run over the entire work at reduced speed, and a flagman was on duty to halt trains, though this was seldom necessary. The hours of most frequent trains were utilized in preparations, and the lowering generally took place between 10 A. M. and 5 P. M., when the travel was lightest. Even at this time trains crossed a given girder at average intervals of about one and a half minutes.

The actual shortening in the length of the grade due to lowering was calculated to be about three-fourths of an inch. It was supposed

that the single bolts connecting the longitudinal girders to the transverse girders might be sheared off by compression. This did not occur, however; the shortening seemed to distribute itself uniformly, and to be taken up by the slotted holes at one end of each span. The rails had been quite tight on the grade and closed together at the summit, with a tendency to spread; about 2 ins. was cut out at the joints at this point, which, with the shortening, expansion and movement of the rails under traffic, was quickly taken up.

When the entire lowering was completed the girders were securely riveted to the long channel of columns, left in place, giving a rigid connection of girders to columns. When this channel extended above the top of girder, as it did in several cases at the old summit, the excess in length was cut off.

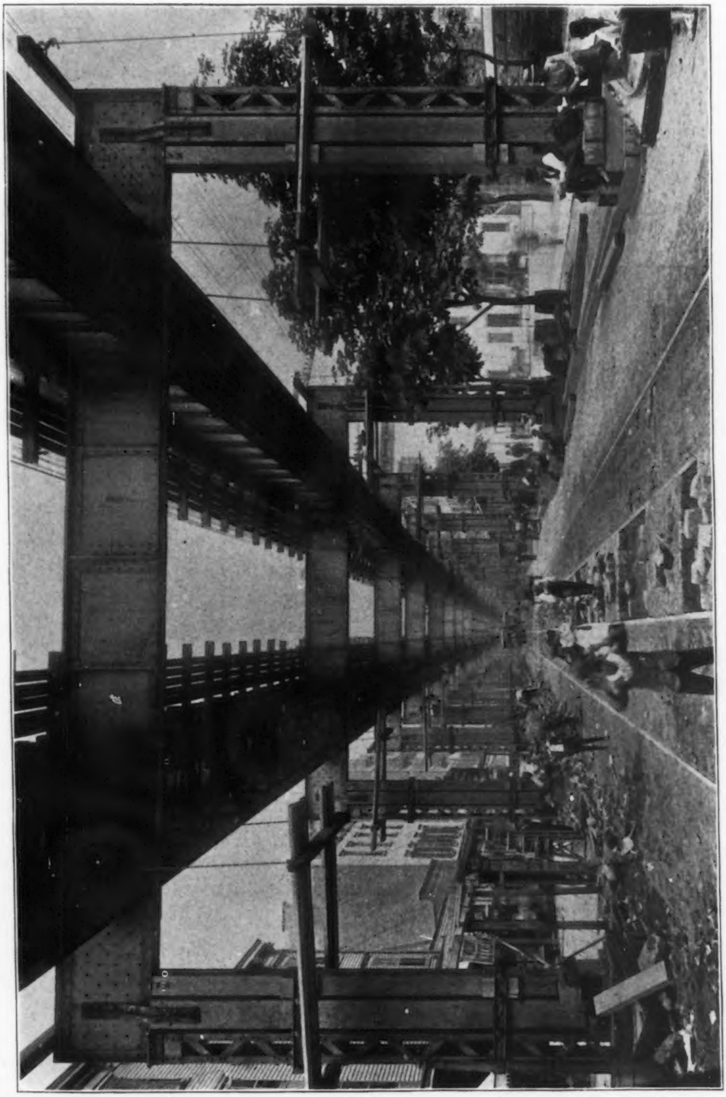
The entire force of men employed in the work of lowering and preparations therefor consisted of 30 men, classified as follows:

Carpenters	2	Riveters (four gangs)	8
Drillers	6	Trackmen, Helpers, etc.	14

When the lowering of the structure was fully completed the 10 girders above Washington Avenue station were raised, and wrought-iron plates or cast-iron blocks were placed on the columns under the girders as required, the maximum amount of blocking being $7\frac{7}{8}$ ins. The grade was thus increased between Grand Avenue and Washington Avenue station from 1.4 to 1.55%, increasing the headroom for the station foot bridge and permitting engines going west to stop and start on a grade of about 1 per cent.

The original intention to retain a third track between Cumberland Street and Waverly Avenue had left the transverse girders at Vanderbilt Avenue strong enough to carry the island station; it was, however, necessary to reinforce the corresponding girders at Washington Avenue and Cumberland Street. This reinforcement was effected by placing a subgirder under the old transverse girder, the adjacent flanges being riveted together. The new grade line as established gave about the same headroom at the other two stations as at Vanderbilt Avenue. All of the track girders required special treatment, to give room for foot-bridge approaches to the island stations. The old track girders must be removed and replaced by new ones, which must be so designed as to utilize every inch of headroom available. The

PLATE LII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.
NICHOLS ON IMPROVEMENT ON BROOKLYN ELEVATED RAILROAD.



peculiar construction of the through-span girders made it possible to arrange the foot bridges so that the distance between the under side of canopy over bridges and base of rail is about $1\frac{1}{2}$ ins. at the center.

The reinforcing girders were placed in position and then the through-span girders were erected, and those on the inside braced by the frames placed between them for that purpose and to sustain a portion of the station floors and stairways. These frames carried a temporary platform on which the floor beams and track stringers were placed and from which they were erected.

The old track girders were to be removed, a single span at a time, and the floor systems of the new spans placed between the hours of midnight and five o'clock in the morning, when trains were running at long intervals, only one train passing in either direction every 15 minutes. Sunday morning was generally selected for this work. The long interval between trains could then be extended until 7 or 8 o'clock in the morning, leaving about seven hours for the work, during which time all trains were run on single track in both directions, crossing over in Grand Avenue just above Myrtle. To complete the work in this way with a single gang of men would require six weeks for track work alone. Two gangs were organized with duplicate tools, and after the men had become experienced in the work, a span was also changed in the middle of the week, an interval being allowed for the men, who were generally employed during the day on other work, to rest.

The old track system having been removed with the lateral bracing and fastenings of the track girders, they were lowered to the street by the use of two gin poles resting on the ground and lashed to the transverse girders; these same poles had been used in raising the through-span girders. The falls were operated by hand winches on the street. The heaviest through-span girder weighed 14 000 lbs.

The old track system and girders once out of the way, the floor beams and stringers of the through span were lowered into position by hand-falls from a small *A* frame resting on the girders. When these members were secured, the new ties and rails were laid in place and connected up. This work of changing the entire track system and supports on spans about 60 ft. long in from six to seven hours was probably the most trying and expeditious of all the work done on the improvement. Only 8 or 10 men could be used to advantage, and they

had to be riggers, fitters, riveters, carpenters and track-layers, all at one time.

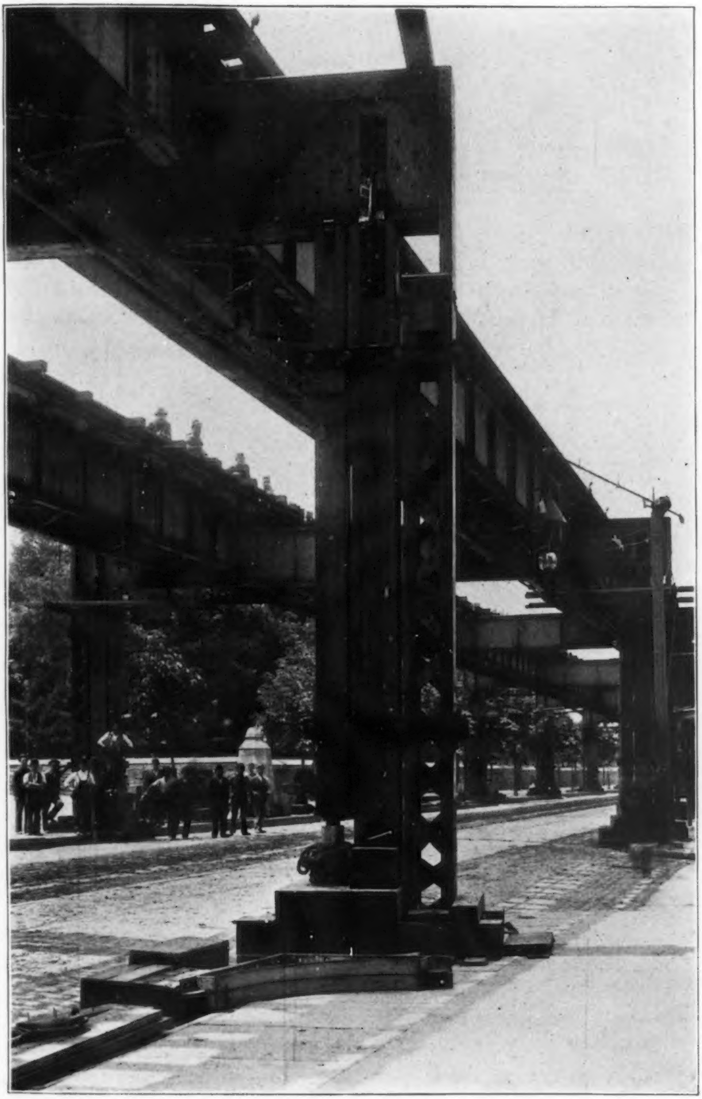
Eighteen other girders for new platforms weighing about 7 000 lbs. each were placed in position. These girders were old track girders from another portion of the road; the old platform girders being too light for the work, these girders were braced with new material. Thirty-two of the old platform girders, each weighing about 4 000 lbs., and the eighteen girders for new platforms were all handled with greater ease by the use of a short boomed derrick, working from the center over the side of a flat car on which it had been erected. All of the heavy material was delivered on the street and carted from and to this position on heavy trucks, the new material arriving by lighter at a dock about one mile from the work, and the old material going to the company's yard about five miles distant. Most of the handling and carting of this material had to be done at night when the street and railways were not so busy. This increased the expense and retarded the work.

The two old station buildings at Washington Avenue were used for the new stations, one at Washington Avenue and one at Vanderbilt Avenue, the two old buildings at Vanderbilt Avenue being abandoned and torn down.

The station buildings to be moved were raised up from their floors, slid over on rail skids to a heavy flat car moved by locomotive to the new positions, where the buildings were slid over into place and dropped down on the new floors previously prepared to receive them. The buildings had angle iron frames with corrugated iron sides and tin roofs laid on spruce boards; the inside was ceiled throughout with yellow pine ⅞ in. thick. As moved, the buildings weighed about 15 tons. The ticket offices and closets were removed and the doors and windows left in place. Light needle beams formed a frame on which the buildings rested in moving, while the raising, lowering and sliding were done with 10-ton hydraulic jacks acting against 8 x 10-in. sticks bolted across the ends of the building about 3 ft. above the floor. The car used for transportation was built for surface roads, and the heavy load set the body hard down on the s .e bearings. It passed easily around the curve at Clinton Avenue, and no trouble was anticipated at any other point.

Provision was made to accommodate passengers at the stations dur-

PLATE LIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.
NICHOLS ON IMPROVEMENT ON BROOKLYN ELEVATED RAILROAD.



ing the changes; no station was absolutely closed to business excepting during the hours from midnight to six o'clock A. M. of the two nights when the buildings were being moved.

The work of changing the stations moved slowly, of necessity; the station girders were not placed until the re-enforcing girders, ten in number, were completed. The buildings could not be moved until all the girders were ready, and much of the carpenter work and sheet metal work and all the plumbing and painting was dependent on progress made with work preceding. Injunctions were obtained in two instances, but no serious delay in the opening of the new stations resulted in either case. Washington Avenue station was finally opened as an island station on October 17th, and Vanderbilt Avenue station on November 1st, 1893.

ITEMS.	Total expenditure.	Lowering structure. Bents 68 to 92.	Changing stations and changing grade east of Washington Avenue.
Engineering and supervision	$1 705 06	$560 00	$1 145 06
Timber for false work	1 025 25	2 354 13	997 29
Tools and other appliances	2 326 17		
New iron work left in structure	11 051 20	193 70	10 857 50
Cartage and transportation	1 027 87	138 37	889 50
Moving electric wires, etc	508 35	200 00	308 35
Labor account	10 011 79	2 545 22	7 466 57
Personal injuries	3 50	1 00	2 50
Changes in station building and stairs:			
Iron work	5 515 58		
Carpenter work	4 547 54		
Roofing and sheet metal work	1 465 11		
Plumbing	272 39		
Painting	666 93	....	12 467 55
Total work completed	$40 126 74	$5 992 42	$34 134 32
Estimated cost of completing Cumberland Street station:			
Erection of stairways, etc	600 00		
Carpenter work	3 000 00		
Sheet metal work	900 00		
Plumbing	300 00		
Painting	400 00		
Heating apparatus	200 00	....	5 400 00
Grand total	$45 526 74	$5 992 42	$39 534 32

New station buildings would have been more commodious and ornamental than the old ones; about $3 000 was saved, however, by the use of the old buildings, which, with extensions and other changes made, satisfy all the ordinary requirements. The canopy posts from the old

station platforms were again used, the canopy trusses and roofs being new.

Only one accident occurred on the entire improvement; a man fell in securing one of the re-enforcing girders at Cumberland Street and was slightly injured.

Great credit is due to the workmen employed for skill and zeal displayed. The roadmaster deserves special commendation; he was almost continuously on the work in its serious stages; his familiarity with the movement of trains and handling of men and material was intimate and thorough, and he devised many expedients of great service in avoiding delay and expediting the work.

The cost of the entire improvement was as shown in table on page 373.

No allowance whatever has been made for tools and material left over from the work, which will be valuable for other work.

The following figures have been made in the endeavor to ascertain the value of the improvement to the road. Aside from the semi-sentimental betterments, that no uncertainty can now arise as to which stairs to take for up or down trains, and that passengers are often spared the necessity of crossing crowded or muddy streets, aside from all this, what has been saved?

The direct saving from the change to island stations may be placed as follows for the two stations:

Services of four station agents, for two stations, at \$1.75	\$7 00	per day
Heating and lighting, two stations, at 50 cents	1 00	"
Total saving per annum, \$2 920, at	\$8 00	"

The annual interest at 5% on the cost of the work to date is \$2 006 34, that is, the saving at stations alone would have paid the interest on the entire cost if it had been 45% greater; or the saving from the change of stations would have paid the fixed charges due to these changes and carried those of the cost of change of grade if the latter had cost four times as much as it did.

There must be a positive economy in the operation of trains due to the lowering of the grade; it is, however, difficult to determine its equivalent in dollars and cents. Considering only the power required to lift the trains on the two grades, we know that where trains were formerly lifted vertically $14\frac{4}{10}$ ft. in 770 ft., they are now

lifted the same height in 1 330 ft. The mean of many observations placed the speed of ascent at 15 and 18 miles per hour respectively. Formerly the trains were lifted in $\frac{583}{1000}$ minute, and they are now lifted in $\frac{839}{1000}$ minute, the horse-power developed in the two cases being 104.8 and 72.8, taking the weight of each train at 70 tons, including engine. It was necessary to maintain 32 H. P., or 44% greater efficiency in the engines on the old grade than on the new one, to accomplish the same work of lifting the train $14\frac{1}{10}$ ft., the resulting gain being due to the lengthening of the time in which the work is done.

About 400 trains are lifted every day, and the additional power was maintained for every train. We do not know just what this class of power costs per unit; it probably is not less than the average cost of the unit horse-power maintained for all the engines on the road in regular service, and this average cost approximates to $\frac{25}{1000}$ cent per horse-power. On the assumption that this figure will cover the cost per horse-power, the cost of maintaining the additional power required for the old grade would be $\frac{8}{10}$ cent per train and the saving due to the change of grade will be $\$.008 \times 400 \times 365 = \$1\,168$ per year.

If, now, this sum be added to the saving from changing the two stations, the total saving will be \$4 088, and the money would have been well invested had the improvement cost twice the amount actually expended. It also appears from these figures that the change of grade would have been a profitable one to make if it had been done of itself at four times its actual cost.

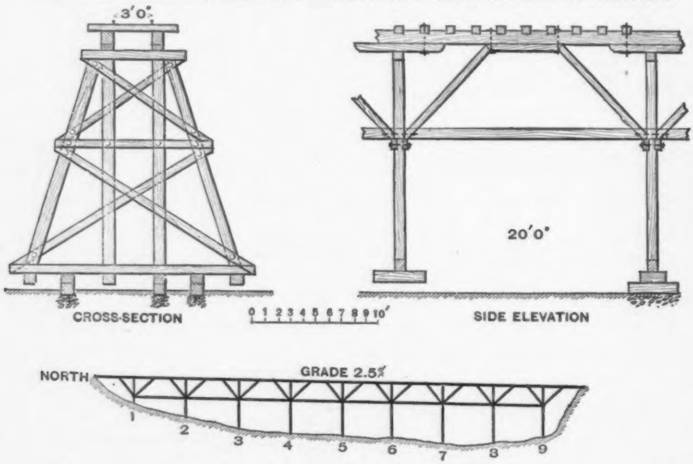
As to the Cumberland Street station, 15% of the business done at Vanderbilt Avenue station will meet the fixed and operating charges due to completing and using the new station.

The only serious objection to opening this station at once is the expense and delay due to making train stops. There can be little doubt that this objection will soon be overcome by the increase of business, and that it will be found expedient and profitable within a reasonable time to complete the station for use. Should this station, when opened, be ordinarily successful and do two-thirds only of the business done at Vanderbilt Avenue, it will, itself, earn 125% annually on the cost of the change of grade, and 20% on the cost of the entire improvement.

DISCUSSION.

Emile Low, M. Am. Soc. C. E. (by letter).—Mr. Nichols' paper brings to my mind an experience I had some 16 years ago (1878) in lowering a trestle on what was then known as the Pittsburg Southern Railroad, successor to the Pittsburg, Castle Shannon and Washington Railroad, a narrow-gauge line between Pittsburg and Washington, Pa. A portion of this railroad now forms part of the Wheeling Division of the Baltimore and Ohio Railroad. The trestle in question was situated about 1 mile south of Thomas Station, and on a descending grade, going south, of 132 ft. to the mile.

PITTSBURG SOUTHERN R.R. PLAN SHOWING METHOD OF LOWERING HAMILTON TRESTLE 2.



The standard trestles of the Pittsburg Southern Railroad were built to the following general dimensions : Span, center to center of bent, 20 ft.; plumb and batter posts, 10 × 10 ins., the batter of the latter being 4 ins. to the foot; stringers, 10 × 12 ins., strengthened by long corbels and knee braces. The foundations were usually mud blocks or sills, resting upon broken stone.

The proper elevation of the mud blocks was indicated by suitable stakes driven in the ground at each end of the sill, the top of the stakes corresponding to the bottom of the sill. In setting the stakes for this particular trestle, through the inadvertence of one of the assistant engineers, the stakes for bent No. 7 were driven, and their tops left 1 ft. too high.

The foreman in charge of the carpenter force erecting this trestle began at bent No. 9, which was properly erected, as was also bent No. 8. When bent No. 7 was set up, of course it was too high. Bent No. 6 came next, and was again correct. The foreman, without consultation, and on his own responsibility, raised bent No. 6 to come in surface with bents Nos. 7 and 9, and then raised bent No. 8 to suit.

It may be remarked here that none of the engineering force of the railroad were on the ground during the erection of this trestle, or this would never have occurred. Bents Nos. 5, 4, 3, 2 and 1 were raised in order, and of course did not line on account of the new order of things. Nothing daunted, the foreman raised these last ones, being possibly two or more feet too high at the north end.

Proper stakes were driven at each bent, and why the foreman did not notice that by lowering bent No. 7 everything would have come all right baffles explanation. The consequence was that the whole trestle was cocked up on a row of blocks, some 2 or 3 ft. high.

The erection of the trestle only occupied a few days, and its peculiar arrangement was noticed by me on a trip over the line a few days after its completion. The carpenter force had been disbanded. It was my desire to put the trestle where it properly belonged, and this work I accomplished as follows : The only force I was able to command was an Englishman, named Burton, and his two sons, the owners of a few horses and carts, which had been engaged on the work of grading of the same road.

My first instructions were to obtain from a neighboring saw mill a supply of 1-in. boards, which were sawed in lengths varying from 2 to 4 ft. Fortunately none of the elevation stakes set for the bottom of the sills had been moved. These were duly pointed out to my man, and their purpose fully explained.

Then I further instructed him to take out one by one the mud blocks, lower each to its proper level on the broken-stone foundation, and then carefully fill up the intervening space with the 1-in. boards, using the longer ones at the bottom, the shorter ones on top. As soon as one block was properly fixed, another block was taken out, placed in position, and the space filled up with 1-in. boards.

This procedure was followed until every block had been correctly placed, the trestle then remaining as originally erected, except that it was resting upon these 1-in. boards, and these in turn on top of the mud blocks.

The most difficult part of the work yet remained, and that was the removal of the boards and the consequent lowering of the trestle. No appliances of any kind were at hand, such as jacks, etc.

Recourse had to be had to long, heavy levers, cut from trees in the vicinity of the trestle. With these and blocks for fulcrums, the 1-in. boards were gradually withdrawn, thus lowering each bent in

turn 1 in. This method was kept up until the trestle rested upon its final foundation, and was true to the original contemplated grade. I was not present when the work was done, but it was entirely performed by the three men mentioned, none of whom were carpenters, and had never been engaged in work other than that of grading.

The work was so skillfully executed that not a joint was opened in the entire structure. Trains were running over the trestle during the whole time that the work of lowering was in progress. The work only occupied a few days, and the resulting expense, I suppose, did not exceed \$20 to \$25.

JOHN THOMSON, M. Am. Soc. C. E. (by letter).—In regard to the closing paragraphs of this paper, I do not think that Mr. Nichols claims enough advantage for the work accomplished. As I understand it, however, the data furnished are not sufficient for a proper comparison. But from an assumption based upon the figures of his paper, I find that the advantage measured in point of time is about 20 per cent. Thus, it is not stated whether there has been any diminution in the speed of approach of the new grade. If so, this would be an element of advantage to the new. Neither do I find the time given for traversing the level stretch of 560 ft. after the old grade had been passed. On the assumption of a uniform rate of 15 miles an hour, however, and taking 0.583 minute for the old grade with a distance of 770 ft., and of 0.839 minute for the new grade with 1 330 ft., this would make the time for the difference in distance 0.424 minute, or 1.007 minutes for the entire distance. Hence, 1.007 — 0.839 gives 0.168 minute, or $\frac{.168}{.839} = 20\%$ advantage in time. And this is, by the way, a proof of the train speeds quoted, namely, 15 miles an hour for the old grade and 18 miles an hour for the new; that is an advantage in speed, on grades, of 20 per cent.

Of course, my only object in this is to bring out the additional data which evidently are necessary to give a more satisfactory solution; because, judging the moving of these trains as if they were, say, the sliding block in a cam, then I am quite of the opinion that there would be a greater actual advantage than is claimed by Mr. Nichols. And I may suggest that the expression of raising the train through the height of 14.4 ft. is somewhat misleading unless closely associated with the two elements, time and linear space; because, if it were simply a question of vertical height and time, then the work, in foot-pounds, necessary to elevate the trains vertically could probably be otherwise accomplished at less expenditure than by running the trains over a linear distance of 700 to 1 300 ft.

Were any indicator tests made of the engines while traversing these grades before and after? Would not this have told the story pretty effectively in terms of coal consumption?

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E. (by letter).—While the paper by Mr. Nichols is interesting and instructive in its record of the design and carrying out of an engineering work, it seems to me that its chief value lies in the references and calculations made as to the economic side of the questions involved. We see constantly in Society transactions and technical papers the descriptions of works designed and constructed, but it is rarely that the writers present or discuss the economic points. While it would not be fair to assume that they have ignored this side of the subject, it seems certain that railway economics and engineering economics (not economies) are not studied as they should be.

Taking this question of the stations of elevated railways, it is not likely that the economics of station arrangements were gone into in the original laying out of these roads, or, with such results as those given by Mr. Nichols, it would probably have been decided to build more stations on the island plan, though, of course, local conditions prevent the adoption of any one standard throughout. The Chicago and South Side Railway, which owns its right of way through the blocks, has its stations under the structure, on the street level, so that only one ticket agent and ticket chopper are required, while at the same time a separate platform is retained for each track. It is also worthy of note that the New York elevated roads have one station in a building on the street—the ticket offices, etc., of the Fulton Street station being on the second floor of the United States Hotel building, from which there are passages and stairways to an island platform. The substitution of turnstiles for ticket choppers is another question in the economics of operation.

The paper also brings out the fact that many comparatively small works involve much study and many difficulties. Thus, while the change of grade was in itself no great work, yet the carrying out of a complicated series of operations so as to avoid interference with the heavy traffic made it necessary to foresee and provide against many possible troubles, and especially made it necessary to have a well-organized gang. As shown by the paper, only a limited number of men could be worked, and they had to be able and ready to turn their hands to all sorts of work; while, during the operation of lowering, it was necessary that each man should know his particular duty and do it at the proper time. Upon the organization and handling of gangs for difficult work depends much of the engineer's success, and it should not be forgotten that to such gangs belongs a good share of the credit for the execution of many of our important works.

J. J. R. Croes, M. Am. Soc. C. E.—The author's description of the methods employed in the carrying out of the work of construction is exceedingly interesting and very valuable for reference. The difficult work of lowering a long section of elevated railroad track without inter-

fering with the passage of trains is so clearly and fully described that there does not appear to be any comment necessary, and criticism of the methods cannot well be made by any one without knowledge of the circumstances attending the work. So far as can be judged from the paper, the work seems to have been executed with good judgment throughout. The advantages to be gained by having intertrack stations on a line of city transit are not overstated by the author, provided the circumstances are such as to permit of their being used to advantage, and with increase of travel the advantages of intertrack stations are greatly increased. This is chiefly due to the less number of men necessary to be employed at the stations. At stations where the traffic in both directions is very heavy, an intertrack station is very much to be preferred as affording opportunity for the construction of exit platforms on the outside of the tracks, enabling passengers to pass out from the trains without interfering with the incoming passengers. This, to be sure, has not been taken advantage of in the existing elevated railroads on New York island, the intertrack stations of which are provided only with one platform, with the result of great confusion and interruption to both incoming and outgoing passengers. It is said to be stated by officers of the roads that the objection to the construction of such outside exit platforms is that the owners of adjoining property would claim additional compensation for the supposed obstruction to light and air caused by their erection.

The relative cost of intertrack and side-track stations is exemplified by the annual reports of the various elevated railroads for the year 1891, as follows: Suburban Rapid Transit Company, operating 4 miles of line with 11 stations, all intertrack, carried 10.74 passengers per train-mile, and the cost of station service for each station was $2 064. The Kings County Elevated, operating 8.34 miles of line with 24 stations, mostly side track, carried 13.71 passengers per train-mile, and the cost of station service was $3 921 41 per station. The Brooklyn Elevated Railroad, operating 17.93 miles of line, carried 12.27 passengers per train-mile, and the cost of station service was $2 537 24 per station. The Manhattan Railway operating 32.40 miles of line, with 98 stations, carried 23.77 passengers per train-mile, and the cost of station service was $5 909 62 per station, all but six being side-track or double stations. Making every allowance for increased cost due to additional travel, the maintenance of intertrack stations cannot be other than much less than that of side-track stations.

But it must be borne in mind that intertrack stations necessitate the occupation along the whole line of a much greater width of right of way, and that they interfere very materially with the possibilities of real rapid transit on a long line, for the carrying out of which a third track passing by at least three-fourths of the stations without stopping is necessary. It is true that in localities where a large amount

of long distance travel in both directions simultaneously exists, four tracks are necessary, or an entire double system, but where, as in both New York and Brooklyn, the great bulk of the travel during two or three consecutive hours is in one direction, only three tracks are really needed, and, in any street which is wide enough to accommodate three tracks at all and rapid transit is essential, it will prove cheaper and better to space the tracks for ordinary traffic far enough apart to admit of the laying of a third track between them, and to put the stations outside of the tracks and not between.

As regards the increased economy in operation of trains due to the reduction of grade, the argument appears to be more theoretical than practical when applied to elevated railroad service where the runs are so short between stations and the speed of the train must be checked before the effective capacity of the locomotive for a long run has been reached. That the coal consumption of engines ascending the grade would be somewhat reduced by the flattening of the grade, there can be no doubt; but it is a question whether that is not balanced by the increased consumption necessary in operating trains in the opposite direction. Whether the change of grade has resulted in diminishing the coal consumption in the locomotives can only be discovered by comparing the consumption of coal during any six months since the change of grade with the coal consumption on the line during the same six months of the year preceding the change of grade, not with the six months immediately preceding the change, for the consumption of coal by the elevated railroad locomotives varies very much with the temperature of the outside air, and the amount of coal consumed per mile during the different months of the year varies almost directly as the mean of the thermometer for those months. The attempt to calculate theoretically the amount of saving effected in horse-power and in cents per horse-power without having any actual figures of results obtained by which the computations can be verified, introduces into this eminently practical and instructive paper a hypothetical element which might with advantage be omitted.

H. W. Brinckerhoff, M. Am. Soc. C. E.—In estimating the economy in operation, due to the flattening of the grade which the paper describes, the author asserts that "it was necessary to maintain 32 H. P., or 44% greater efficiency in the engines on the old grade than on the new one to accomplish the same work." He then assumes that the cost per unit of the horse-power thus saved is equal to "the average cost of the unit horse-power maintained for all the engines on the road in regular service," which he gives at $\frac{25}{1000}$ of a cent.

To take up the last point first; in response to an inquiry from the writer, the author says: "The cost of the unit horse-power was obtained by dividing the cost per train-mile by the horse-power developed per mile." Just what "horse-power developed per mile" can mean, or

why it should be any different from horse-power developed per inch, is not at all clear, especially when it is considered that the cost per train-mile is, within ordinary limits, not materially affected by the rate of speed, while the horse-power is very closely proportional thereto, so that, by the author's method of computation, the less the speed, the more it costs per "unit horse-power."

If we take 50 cents as probably a reasonable figure of cost per train-mile for 70-ton trains, we will find that for a cost per "unit horse-power" of $\frac{25}{1000}$ of a cent, there must be $\frac{50 \times 1000}{25} = 2000$ H. P. "developed per mile," suggestive, perhaps, of 50 engines developing 40 H. P. each, as at an average tractive resistance of 10 lbs. per ton, a 70-ton train would, at 20 miles per hour, or 30 ft. per second, require nearly 40 horse-power $\left(\frac{70 \times 10 \times 30}{550} = 38 \text{ H. P.}\right)$ for its propulsion.

It is, however, hardly worth while to spend time in conjectures as to what such unusual expressions and computations may be imagined to mean when the fundamental statement is so obviously erroneous. The old grade did not make it necessary to maintain 32 or any other horse-power more or less than the new one. The horse-power required to ascend a grade with a given load depends just as much on the speed as on the steepness. If made so steep that the engine can barely crawl up, it may take much less horse-power to ascend a given grade than if made so flat that practically full speed could be maintained, which, according to the author's mode of reasoning, would prove the economy of heavy grades. To take the case in point; if the speed had not been increased after the grade was flattened, only 60.6 H. P. would have been required to surmount it, and a much greater economy could have been figured out, while, if the speed had been increased to 26 miles per hour, the new grade would have been surmounted in the same time that the old one had been, requiring the same horse-power, and, consequently, showing no economy whatever, and a still higher speed would show a positive loss.

This ought to be enough to show the fatal fallacy of this mode of reasoning, which seems to be based on the assumption that horse-power is, in itself, a measurable quantity, and, as such, can be saved, with a resulting cash gain; whereas, horse-power is merely a rate of doing work, and can no more be saved or accumulated than a rate of interest can be deposited in a savings bank. It must follow, also, that, as horse-power is not a quantity, it can have no real unit, and that all calculations involving a "unit horse-power" as something different from 1 H. P., are meaningless and misleading. The only real and valuable quantity dealt with in the foregoing calculations is the train-mile. This represents work done, and, if our previous assumptions are correct, equals $70 \times 10 \times 5280 = 3700000$ ft.-lbs.

It will be noted that the correctness of our reasoning is in no way dependent on the correctness of these assumptions, which are merely used for convenience of illustration. Indeed, while 10 lbs. per ton is, perhaps, ample for the average resistance of a moving train, even including grades, it would, for elevated roads, have to be largely increased, perhaps even doubled, to allow for the large amount of energy that is absorbed by the brakes in the frequent stops, and which has to be redeveloped by the engine in getting up speed each time.

The work done by the engine in one ascent of the grade is obviously $70 \times 2\,000 \times 14.4 = 2\,016\,000$ ft.-lbs. plus the train resistance multiplied by the length of the grade. As the sum of this latter quantity plus the resistance on the level track is necessarily a constant, and the former quantity is independent of the steepness of the grade, it follows that, if we leave out the saving in repairs due to shortening the time of maximum effort for the engines, the actual economy effected by this particular flattening of grade is that due to the shortening of three-fourths of an inch in the total length of the line. As this is effective both ways, or for 800 trains a day, it would give in a year $\frac{3 \times 800 \times 365}{4 \times 12 \times 5\,280} = 3\frac{1}{2}$ train-miles, or to be liberal, an annual saving of, perhaps, $2.

G. Leverich, M. Am. Soc. C. E.—It would seem that engineers who are not locomotive runners are likely to be confused by the trend of this discussion. Generally, there is no difficulty going down hill; it is going up hill that causes trouble, and yet one may conclude from what has been said that the degree of grade to be overcome is unimportant, which is a manifest error.

On any railway line, the maximum grade determines the hauling capacity, and consequently the weight and steam-making power of the locomotives to be used, and they will be worked with the greatest economy, taking into account the costs of operation and repairs, and their length of service, when this grade most nearly corresponds with the profile of the other parts of the line. An abatement of grade may, therefore, permit the selection and use of locomotives more nearly adapted to the general work of the railroad than otherwise were possible.

Virgil G. Bogue, M. Am. Soc. C. E.—I would like to ask Mr. Nichols, if the time referred to in each case would bring his train out to the same point? If not, there must be a certain expenditure of horse-power in going over the level track, which, it seems to me, should be added to the smaller sum total of horse-power to get a perfect result. This would reduce somewhat the saving.

I think the paper is a very complete one. The question of repairs of these stations has been left out of consideration; I should think that the repairs of an island station would be somewhat less than for a double station.

G. H. Blakeley, Jun. Am. Soc. C. E.—I think that we can, in this discussion, refer with profit to common experience. Suppose we have a weight to raise to a fixed height in a definite time, and we are using an engine which can just accomplish it, if the time of the lift can be extended twofold, we certainly can employ an engine of half the power. This is self-evident. In either case the amount of work done is the same, as the product of the weight by the distance raised is the same for both instances, or, mathematically speaking, the number of foot-pounds of work accomplished is identical. The horse-power in the second instance is only one-half of that employed in the first case. The horse-power is not a measure of the amount of work; it is a measure of the rate of doing work.

The subject under discussion presents a similar case. The weight of the trains and the vertical distance raised, remain the same. The only factor that is changed is the time, which has been increased. The amount of work done remains the same. The change is in the rate of doing it.

A pound of coal represents a certain number of heat units, a certain number of foot-pounds of work. Theoretically, the consumption of coal necessary to accomplish a certain definite amount of work is calculable and does not depend on the rate of doing the work. It requires about 4 pounds of coal per hour to develop 1 H. P. In the instance under discussion, before the grade was changed, it required 104.8 H. P. acting $\frac{583}{1000}$ minute to lift the train 14.4 ft. The coal consumption would then be:

$$\frac{104.8 \times 583 \times 4}{1\,000 \times 60} = 4.07 \text{ lbs.}$$

In the second instance the same train is lifted the same height in $\frac{839}{1000}$ minute, using 72.8 H. P. The amount of coal consumed will then be as follows:

$$\frac{72.8 \times 839 \times 4}{1\,000 \times 60} = 4.07 \text{ lbs.}$$

As was to be expected the coal consumption is the same in either case.

From the facts developed by the discussion it seems quite evident that under the old condition the engines were worked up to, if not exceeding, their capacity. The easement of the grade reduces the energy required, and should practically result in a saving in the amount of the annual repairs to the locomotives. It is not an easy matter to determine how much this saving is, but it is certainly not inconsiderable in this case.

P. F. Brendlinger, M. Am. Soc. C. E.—Mr. Nichols has given the Society this evening a rare treat. He has shown us a practical illustration in detail, of performing, of what no doubt seemed to him, a very difficult undertaking, and the problem no doubt caused him long

hours of serious study. Yet, like many other problems, it seems easy and simple after the work is completed.

The winding up of the paper where Mr. Nichols goes into the theoretical and determines the amount of coal saved by the change of grade seems to my mind to introduce a problem that can only be solved by actual trial on grades much longer than the one changed. If, for example, we have a grade of 2 ft. per 100 ft. for 1 mile, and another of 1 ft. per 100 ft. for 2 miles, both grades on a tangent, we could then by trials demonstrate practically whether the coal consumption on one grade would be greater than the other, but in this paper we have the grades extending only 770 and 1 330 ft., hence the problem is rather difficult to solve practically.

Theoretically we have the same amount of energy expended to lift the train whether the work is performed in 770 ft. or in 1 330 ft., the height to which the load is lifted being identical in both cases. The ratio of work performed per foot horizontally on the two grades being as 1 330 is to 770, or, approximately, 73% greater on the heavier grade than on the lighter. Practically we find the case is somewhat different as the resistance of the train is not double on a 2% grade what it is on a 1 per cent. The resistance due to the grade alone is always at a uniform ratio, but to each amount due to the grade must always be added the constant due to the horizontal resistance.

Thus while a 2% grade gives 40 lbs. resistance per ton per foot raised, and a 1% grade 20 lbs., yet, owing to the horizontal resistance, we have, on a 2% grade, a resistance of 47 lbs. per ton at a 15-mile speed, and 27 lbs. per ton on a 1% grade. In calculating the resistances on the old and new grades of the Myrtle Avenue line, I will take the average of both grades. I find in one case the elevation of 14.4 ft. is overcome in 770 ft. or at the rate of 1.87% grade per 100 ft. In the other or new grade the 14.4 ft. overcome in 1 330 ft. or 1.08% grade per 100 ft. The resistance of the train on the heavier grade at a speed of 15 miles per hour is about 45 lbs. per ton and on the lighter grade about 29 lbs. per ton, or in other words we have practically only 55% greater increased resistance on the 1.87% grade than on the new grade, while as I have shown above that theoretically we have 73% more energy expended on the heavier grade than on the lighter. Now, to overcome the resistance on any grade requires engine pull which is produced by the consumption of coal, water, etc. If the coal consumption is uniform or constant for every pound of train resistance, then the consumption on the lighter grade for 1 330 ft. would be greater than on the heavier grade for 770 ft., but to the coal consumption for the heavier grade must be added the consumption of coal due to the resistance of 7 lbs. per ton on the 560 ft. of level grade. This may bring the total coal consumption greater on the old than on the new grade. As I have before stated a trial of considerable length of

time on long grades, is necessary to determine whether any coal is saved on grades as herein mentioned.

There is no question in my mind that an immense saving in engine wear, running of trains, etc., results in having the grade changed, and much heavier trains can be hauled over the road if there are no other grades on the road as heavy as the one that was changed. As to a saving of coal I leave that to the actual practical demonstration in a year's operation of the road.

W. E. Belknap, Jun. Am. Soc. C. E. (by letter).—The term "horse-power" expresses a rate, a number of units of work expended in a unit of time, 33 000 lbs. lifted 1 ft. per minute. To store up or save in bulk a rate of work is as inconceivable as to store up and save in bulk a rate of interest.

The work expended in moving a train in the same direction between any two points on a road is always equal to the horizontal resistance—the friction over the horizontal distance—plus the vertical lift, a result not at all affected by changes of grade between these two points so long as they retain their relation of altitude. How it can be shown in this case, using the factors of time, weight, horizontal distance and lift, that any work is saved is difficult to see.

That there was a small saving of coal due to this reduction of grade is highly probable. It is a quantity whose determination depends on a comparison of the efficiency of the engine on the original grade with its efficiency on the new grade.

Assuming that the engine was designed to work at its highest efficiency under the probable average load, then (taking the train weight to be always the same) there must be some one certain grade on which that load would always obtain, and on any other grade the load would be more or less than this—that is to say, there is only one grade on which the engine will work at its highest efficiency, and this is the grade which was probably assumed by the designer of the engine when he considered the question of efficiency. Any change in the grade in question bringing it nearer this assumed grade obviously betters the working conditions of the engine, gives it a higher efficiency for the period of time it is on the grade than it had before; and since in the end the same distance is traversed, the same altitude attained, the same work done, there will be a saving of coal in proportion to the increased efficiency on the new grade. How much it would actually be in practice under the ever-varying conditions of wind pressure, number of passengers, speed, temperature, etc., would be very difficult to determine unless the old grade had increased the load far beyond the efficient working capacity of the engine.

O. F. Nichols, M. Am. Soc. C. E.—The cost of operating railway grades has received much attention, without, however, developing results directly applicable to the example presented in this paper.

Some of the literature on the subject is verbose and confusing, often speculative and sometimes erroneous. The difficulty of avoiding these stumbling blocks is apparent from the discussion in hand. It would seem unwise to cumber the record with explanatory matter, and far better to allow misinterpretation, and even misstatement, to go unquestioned than to enter upon a disputation interesting only to the disputants.

The economy claimed for the change in grade is believed to be conservative, if not far within limits, and was somewhat cautiously enunciated in the hope that the author might himself be instructed by those more experienced and skilled in the theory and practice of railway construction and operation. In this respect the discussion has fallen far short of the expectation.

It is simply astounding to find engineers contending that nothing has been saved by this reduction of grade, that indeed one grade is just as economical as another, if not a little more so. This suggests the question, whether the trunk lines are not wasting millions of dollars in simply lengthening the distance in which elevations are overcome on their lines. After such an exhibition, one does not so much wonder that many glaring errors occur in the use of grades, or that railway operating expenses vary so much.

There seems to be a confusion of ideas in the minds of some of the contestants as to the fundamental principles of the problem presented. That the entire work in foot-pounds exerted in raising the trains is the same, regardless of percentage of grades, is elementary, if not axiomatic. As in all similar problems in mechanics, time is quite as important as distance and weight, and is the very bone and sinew of this matter.

Our friends fail to realize that horse-power has no existence without time, that it is a measure of work because it is itself work; not merely something evanescent and inscrutable, but something tangible and real, that may be bought and sold by the day or year, by the inch or mile, or by any other standard which has time as one of its functional elements; that, if it cannot be stored up or deposited in a bank, it costs just as much as if it could, in the daily and yearly barter and sale of the commercial world.

In some recent dynamometric experiments in France the results are given in horse-power per ton of train in ascending grades at various speeds. They show, among other things, that the horse-power required varies very rapidly with the speed. Unfortunately these experiments were made on low grades at high speeds, otherwise they would be valuable in this connection; as far as they are applicable to the problem, they tend, in a general way, to confirm the methods used and the results obtained in the paper under discussion.

There certainly is a decided economy in this reduction of grade, and no amount of obfuscation can completely conceal it; like Banquo's ghost, it will not down; it exists like the kernel in the nut, and may be, at least approximately, determined if we have the capacity to crack the

nut. It is minute, perhaps, for each train, and consequently more difficult to find experimentally. If we consider only the saving in coal, and assume the entire amount claimed as saved to be expended in coal, it would correspond to $3\frac{1}{2}$ lbs., or, say, 11 cu. ins. per train, an amount so small as to be indeterminate in any experiment applicable to the case.

The difference in horse-power on the two grades is merely a difference in foot-pounds, divided by time and Watt's arbitrary constant, and should not be confused with engine performance. The engines may, indeed probably do, not develop as much horse-power on the high grade as on the low, but they are longer at it, so that the problem in any form is essentially one of time.

The first calculations for economy by the reduction in grade were based solely on the saving of time due to actual running of trains. The 560 ft. of level track at the summit of the old grade was run at a speed not exceeding 20 miles an hour; the saving of time over the total distance of 1 330 ft. was then about one-tenth of a minute by the new grade. Several hundred hours were thus saved per year; that is, not only do the engines arrive at the summit of the new grade in better condition than on the old one, but they then have considerable available time to their credit. The running time between the two adjacent stations is diminished nearly enough to provide for the dead stop at one of the stations. Taking the average speed at 13 miles an hour and the cost per train-mile of running trains at its actual value, 26 cents, there results a saving of something like \$600 for the change of grade, without considering the horse-power involved.

This first calculation is now given in order that some of its constants may be used in the consideration of one of the suppositious illustrations of the discussion. "Suppose," says one of the contestants, "that a speed of 26 miles an hour is maintained (by some abnormal engine) on the new grade, the horse-power will then be equal on the two grades, etc., etc.; and if the speed be increased above 26 miles an hour, there will result a positive loss," due to the "improvement." The inevitable economy would, under this hypothesis, simply assert itself in another way. If the time spent on the grades is equal, engines on the new grade would have the time of the entire run over the 560 ft. of level track to their credit. This for the year would correspond to 15 295 train-miles, which at 26 cents, as before, corresponds to about \$4 000, from which should be deducted the increased cost of maintaining the speed of 26 miles an hour, and then represents the saving from the reduction of grade, on this supposition.

It should be noted that the obvious saving in coal on engines descending the new grade is not counted in the total saving, its amount being indeterminate. The engines were formerly obliged to run the 560 ft. of level track under good steam-pressure; while now but little steam is required, excepting to control the train, after it has passed the summit of the new grade.